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ON THE STRESSES OF RIGID ARCHES, CONTINUOUS BEAMS, AND CURVED STRUCTURES.*

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Proceedings of the Institution of Civil Engineers (Great Britain).

The Author, in his remarks on M. Gaudard's Paper "On Metal and Timber Arches" read at the Institution of Civil Engineers in December, 1870, described a method of constructing the curve of equilibrium for an arch unequally loaded, with continuous or discontinuous weights, or under oblique pressure.† The following Paper contains the application of this method to the investigation of the Stresses on Rigid Arches, Continuous Beams, and Curved Structures.

As the consideration of the voussoir arch is more simple than that of the rigid arch, it has been thought desirable to give a preliminary illustration of the method, as applied to the case of an arch of masonry subjected to oblique pressure and to the action of a passing load.

VOUSSOIR ARCH.

The arch chosen for examination is that of the Pont-y-tu-Prydd, over the rive Tâfe, in the county of Glamorgan. The following particulars are taken from a description of this bridge given in the minutes of Proceedings of the Institution of Civil Engineers, vol. v., p. 474.

The span is 140 ft., and rise 35 ft. The arch ring is of rubble masonry, of a depth of 2 ft. 6 in. on the face and not more than 1 ft. 6 in. in the body of the arch. The first time the bridge was built the arch failed, by the weight of the haunches forcing up the crown. On being rebuilt, the spandrels were lightened by cylindrical openings, and the spaces between these were said to have been filled in with charcoal. It may therefore be taken as a good example of an arch of small stability.

The curves of equilibrium on different suppositions are shown on Plate 3, Fig. 1, the dotted line (*b*) being drawn as if the spandrels were filled in solid in the usual manner, and the line (*a*) corresponding to the bridge with cylindrical openings, but without any allowance for the lightness caused by the charcoal filling. It will be observed that the openings act as negative weights in changing the form of the curve of equilibrium, and bring it to coincide very nearly with the centre of the arch ring, so that the utility of thus lightening the spandrels is unquestionable. This is confirmed by an examination of the inverse problem, of finding the load at each point from the form of the curve of equilibrium, assuming it to coincide with the centre of the arch ring.

The dotted black line at the right of Fig. 1 shows the line of roadway on this supposition, and the construction, which may be thus shortly explained, is indicated by the dotted lines.

* The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.
† *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., pp. 143—148.

Having divided the semi-arch into any number of portions, in this case ten, each of the same horizontal length, and drawn vertical lines through the points p_1, p_2, p_3, etc., the centres of these portions, draw the line C D tangential to the curve of the centre line of the arch ring at the crown, to represent the line of horizontal thrust. Since the curve of the arch ring is assumed to be the curve of equilibrium, its tangent at B will cut the line C D in a point D such that C D=D B, and this point D will be in the vertical line passing through the centre of gravity of the unknown mass of the arch between B and C.

Draw any horizontal line D′ E, and lines $D'q_1$, $D'q_2$, $D'q_3$, etc., through D′ respectively parallel to $p_1 p_2$, $p_2 p_3$, $p_3 p_4$, etc.; also draw the line E F vertical, at such a distance E D′ from D′ that Eq_1, the part of it cut off by the line D′q_1, may be equal to the height from the soffit to the roadway at the point p'_1, and will thus measure the weight of that portion of the arch acting at p_1. Then $q_1 q_2$, $q_2 q_3$, etc., the parts of the vertical line through E, cut off by the lines D′q_1, D′q_2, etc., will be the heights of the roadway above the soffit at the points p_2, p_3, etc., and if these be set up vertically above the soffit at the different points, the curve line connecting their upper extremities will be the required line of roadway, which, it will be observed, falls considerably below the line of the actual roadway at the part near the openings.

In drawing the above lines, the arch has been divided into portions having equal horizontal lengths, because then the weight of each portion is measured by the height from the soffit to the roadway. This supposes the density of the backing to be the same as that of the voussoirs, which is probably not far from the truth. The pressure has been considered as wholly vertical, or the backing as composed of a number of separate vertical prisms with horizontal bases, through which the pressure is transmitted to the voussoirs, the backs of which may be considered as notched in level steps to receive the bases of the prisms.

But the material of the backing must have some amount, however small, of mobility among its particles, and the back of the arch having an inclined surface, the pressure cannot be quite vertical. In the absence of any information as to the nature of the backing, the small deviation of the pressure from verticality cannot be known, but some idea of its effect may be gained by ascertaining the nature of the change of the curve of equilibrium, on the supposition that the backing, while retaining its density, is a perfect fluid, pressing at right angles to the back of the arch.

Having divided the arch ring into portions of equal horizontal lengths, as a sufficient approximation, the whole mass of each portion may be taken as pressing at right angles to the back of the arch, with a head equal to the height between the soffit and the roadway at the centre of the division.

At any point p, on the left side of Fig. 1, the intersection of the vertical line through the centre of one of the divisions with the centre line of the arch ring, take $p\ s=p'\ s'$, and draw the normal line $p\ t$, and horizontal line $s\ t$. Then $p\ s$ will represent the weight of the portion acting at p, $s\ t$ its horizontal push, considered as a fluid with a head equal to $p\ s$, and $p\ t$, normal to the curve, will be the resultant of these two forces.

The horizontal forces acting at the different points are thus found, and from these, by the method of moments, the vertical height above A of the line of action of their resultant or sum, can be easily ascertained. Draw M N at this height, and from the point M, where the vertical line G M through the centre of gravity of the semi-arch cuts M N, set off M N equal to the sum of the horizontal forces, and draw N O vertical and equal to the weight of the half arch. The line M O will then be the resultant of all the forces acting on the semi-arch, and will be in the direction of the normal to the curve of the arch ring, since the direction of each of the component forces is normal. The line M O will cut the horizontal line through C, the centre of the crown of the arch in some point G′, and the points G′ and A, being joined, G′ A will be the direction of the thrust at A. To find its amount, draw any vertical line $r\ k$ equal to the weight of the half arch, and draw a horizontal line K k L through the point k. From any point G in C G′ draw G L parallel to G′ A, cutting K k in L, and from L draw L H parallel to G′ O, cutting C G produced in H. Then H L will be equal to the resultant M O, and G L will be the amount of the thrust at A.

To draw the curve of equilibrium, set off from H, H v_1 equal and parallel to the force acting at p_1, $v_1 v_2$ equal and parallel to the force at p_2, and continue this con-

struction, which, if correct, will terminate by the end of the last line drawn coinciding with the point L. This force diagram may also be made by plotting the vertical and horizontal components of the separate forces at p_1, p_2, etc., beginning at the point H. The curve of equilibrium can then be constructed by drawing from the point p_1', where the direction of the force at p_1' cuts the horizontal line C H, $p_1' z_2$ parallel to G v_1, to cut the direction of the force acting at p_2 in the point z_2; from z_2 thus found drawing the line $z_2 z_3$ parallel to G v_2, to cut the direction of the force at p_3' in z_3, and continuing this construction, which will terminate by the last line drawn passing through the point A, and coinciding with A G.

The supposition of fluid backing shows a considerable alteration of the curve of equilibrium, and indicates the tendency of the obliquity of the pressure of ordinary backing to make this curve deviate towards the extrados at the haunches of the arch. In the present instance, the effect of the lightness of the charcoal filling at the openings would be to cause a deviation in the opposite direction; so that, in all probability, the true curve is represented by the line (*a*), and the arch has almost all the stability which an arch ring of such small depth is capable of.

In order to obtain a somewhat more definite idea of the stability, it is not difficult to ascertain what change will take place in the curve of equilibrium when a load of known weight passes over the bridge.

It will be explained hereafter that the effect of a load is greatest when it acts about midway between the crown and the abutment, and that the curve of equilibrium for a load considered as the only force acting on the arch is represented by two straight lines, one of which passes through the crown of the arch and the centre of the abutment farthest from the load, and the other line passes through the abutment nearest to the load, and the point where the vertical line through the load cuts the first-mentioned line.

Further, by equation (13), the curve of equilibrium of the unloaded arch will by the loading be altered at every point through a space equal to the vertical distance between the neutral line of the arch and the line of equilibrium of the load, this distance being reduced in the ratio of the horizontal thrust of the load to that of the arch and load.

Draw, therefore, the vertical line *c d* through the load supposed to act at *c*, cutting B C produced in *d*, and join *d* A; *d* A, *d* B will be the curve or lines of equilibrium of the load alone, and if *a b* be drawn vertically, and equal to the load, and *d g* horizontally to cut *a b* in *g*, *d g* will be the horizontal thrust caused by the weight alone. To reduce this to numerical quantities, if in the present instance a load of 5 tons be supposed to act in the line *c d*, the horizontal thrust will be 2.4 tons.

The weight of the semi-arch may be taken at 415 tons, and its horizontal thrust estimated by scale from Fig 1 at 309 tons.

If the vertical ordinates between the curve of the arch and lines of equilibrium of the weight be reduced in the above-mentioned ratio, and superposed on the curve of equilibrium of the arch itself, the alteration of the curve at the point under the weight will, when reduced in the above-mentioned ratio, be 28.5 ft. $\times \frac{2}{3}\frac{4}{11}\frac{4}{13}$, or say 3 in. In like manner, the depression in the middle of the opposite semi-arch will be 10 ft. $\times \frac{2}{3}\frac{4}{11}\frac{4}{13}$, or say 1 inch.

When a weight of 5 tons, therefore, acts on the arch midway between the crown and the abutment, the curve of equilibrium will be raised 3 in. at the part where the weight acts, and depressed 1 in. at the middle of the opposite arch.

As the former deviation is nearly $\frac{1}{9}$ of the thickness of the arch ring, the compression per sq. in. will, by the remarks on Equation (6 *a*), as compared with the uniform compression if the curve of equilibrium were central, be doubled at the extrados, and reduced to zero at the intrados of the arch.

Taking the depth of the arch ring at 20 in., and its width at the crown at 14 ft. 6 in., the uniform compression there caused by the horizontal thrust of 309 tons is nearly 13 tons, and at the point where the weight is supposed to act 14 tons per sq. ft.

During the passage of a load of 5 tons over this bridge, therefore, the extrados at the point under the weight would be sustaining a compression of 28 tons per sq. ft. This result would be to some extent mitigated by the pressure from the weight being conveyed to the arch through the backing, and thus acting on a surface of some extent, instead of a point as supposed.

Friction would not modify the curve of

equilibrium, but it would be of service in preserving the stability of the arch, if in any part the workmanship were so faulty that the joints of the arch were inclined to the normal at any angle less than the angle of friction.

The cohesion of the mortar, after it had properly set, like the elastic forces of a rigid arch, would be brought into action, if the curve of equilibrium deviated from the centre line of the arch ring by more than $\frac{1}{3}$ of its depth. There would then be a tensile stress on the opposite edge of the arch ring, and the cohesion of the mortar would resist this, and diminish to some extent the compression at the other edge.

The nature of the alteration of the curve of equilibrium, on the supposition of the fluidity of the backing, shows that the practice sometimes adopted, of coating the back of an arch with puddle, may be useful in segmental arches of large rise and level roadway, besides making them water-tight. In these, the curve of equilibrium near the abutments descends below the curve of the arch ring, and the partial fluidity of the backing would tend to raise the curve and increase its curvature at these points. There would also be less horizontal thrust against the abutments, since the thrust at A is altered from A G to A G′ by the supposition of the fluidity of the backing. There would thus be a tendency to diminish any injurious stress on the arch and abutments until the mortar had properly set.

RIGID ARCH.

The investigation of the stresses of a rigid arch has hitherto been a subject of considerable difficulty, owing to the intricate nature of the mathematical analysis it is necessary to employ.

The circular rib has been examined by Mr. Wilfrid Airy, Assoc. Inst. C.E., in his recent treatise on "Iron Arches," and M. Gaudard has given, in the Appendix to his Paper on "Metal and Timber Arches," a solution of the case of a circular rib of varying section. The subject has also been investigated generally, and applied in some detail to the case of the parabolic rib, by Dr. Rankine, in his work on Civil Engineering. The results of these authors being expressed in algebraical formulæ, the labor of applying them numerically to trace the variation of stress from point to point is considerable. Still, before the transverse sections of arch ribs can be proportioned to the stresses coming upon them, a knowledge of this variation is indispensable.

In experiments on the strength of materials, it is found that there are considerable differences in the breaking weights of specimens of the same kind of material, although the dimensions of the specimens are identical. This fact, which makes it necessary to employ a large factor of safety in engineering constructions, renders it unnecessary to solve questions of stress with minute accuracy, and the graphic method of solution is generally a sufficient approximation in practice. From the assistance which this method affords in the treatment of voussoir arches by means of the curve of equilibrium, it occurred to the Author that if it could be applied to the investigation of rigid arches, an equal facility of solution would be obtained.

It will now be shown that the method can be applied, and that the stresses at every point of an arched rib admit of being represented by a diagram, so that their changes from point to point can be readily ascertained. Some questions, also, such as those where the form of the rib differs from the circle and parabola, and where the pressure is oblique, which would be almost intractable by analysis, can be readily solved by this method.

The curve of equilibrium of an arch is so constructed, that the pressure at any point in the direction of the curve is combined with the external force acting there. The resultant pressure is in the altered direction of the curve beyond the point. By this construction it will be seen, that the curve is the locus of the resultant of all the outward forces, and since the moment of a resultant is equal to the sum of the moments of its component forces, the "bending moment," or transverse stress at any point, is equal to the pressure in the direction of the tangent to the curve of equilibrium, multiplied by the perpendicular on this tangent, from the point in question. This moment tends to bend the rib in different directions, according as the curve of equilibrium is above or below the neutral line of the rib, or line passing through the centres of gravity of its transverse sections.

A general idea of the nature of the stresses may be given by Figs. A and B, page 65, premising, as will be shown hereafter, that a force acting parallel to the neutral line, at a given perpendicular distance from it, may be considered as equivalent to a force of the same

amount acting in the neutral line, together with a couple, whose moment is the force multiplied by the given perpendicular distance from the neutral line.

The absolute amounts of the stresses may be ascertained by Equation (6 *a*), yet to be given.

1st. The rib is subject to a general compression throughout its whole length to the same extent as if it were a voussoir arch, and the curve of equilibrium coincided with its neutral line. This may be represented by a force F (Fig. A) uniformly distributed over the area of section, and giving rise to the equal forces per square inch represented by the lines *f*, *f*, *f*, acting at the different points of this area.

2d. The rib is subject also to the stress caused by the bending moment. When this acts so as to increase the curvature, in which case the curve of equilibrium descends below the neutral line of the rib, its state of stress may be represented as in Fig. A.

FIG. A.

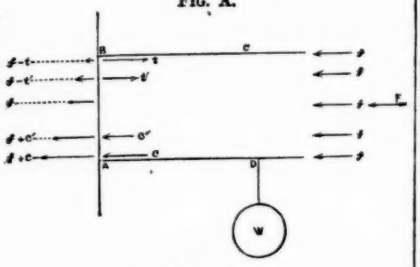
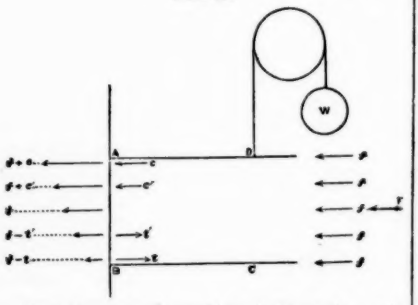


FIG. B.



Any transverse section A B of the rib A B C D is in the same condition as if this section were fixed in a wall, and acted on by the force F, and also by a weight W at a leverage A D, W $\times$ A D being equal to the bending moment, and the total stress at any point is the algebraical sum of the stress due to the action of F, and of that due to the bending moment. This latter will excite tensile forces at the top, and compressive forces at the bottom of the rib, which forces per square inch may be represented on the diagram, Fig. A, by the lines *t*, *t'*, *c'*, *c*. The result of the actions of F and W together is that the stresses at the top are represented by the lines $f-t$, $f-t'$, etc., and at the bottom by $f+c$, $f+c'$, etc.

In like manner, at those points of the rib where the bending moment tends to diminish the curvature, and the curve of equilibrium is above the neutral line of the arch rib, the transverse section A B is in the state represented by Fig. B, the weight W acting upwards instead of downwards, as in Fig. A.

Here the tensile forces are at the bottom, and the compressive forces at the top of the rib, the forces resulting from the action of both F and W being $f+c$ at the top and $f-t$ at the bottom.

The values of *c* and *t* being independent of *f*, $f-t$ may become either zero or negative; that is, the part of the rib to which $f-t$ corresponds may either have no strain or be in tension, according as the tensile force excited at the outer surface by the bending moment is equal to, or greater than, the uniform compressive force *f* caused by the action of F.

In the state represented by Fig. A, the bending moment will in what follows be considered as positive, or tending to increase the curvature of the rib, and in the state represented by Fig. B as negative, or tending to diminish the curvature.

GENERAL CONDITIONS OF EQUILIBRIUM.

For the voussoir arch, the transverse stress which could be overcome by the cohesion of the mortar being so small as not to be worth considering, the curve of equilibrium has generally been assumed to pass through the centre, or, at all events, within the substance of the arch ring at the crown, and its position there determines the horizontal thrust.

But the mode of constructing the curve of equilibrium is independent of its passing through any particular points, either at the crown or at the springing. The points there may be shifted either upwards or downwards, and the curve can be constructed in exactly the same manner, but its figure will be altered by varying the position of these points.

It is necessary to explain the meaning of these changes of position.

When the vertex of the curve at the centre of the crown is raised above the neutral line, it appears by the previous remarks as to the moment of the resultant, that a bending moment will exist there, tending to diminish the curvature of the rib. The horizontal thrust will also be diminished, since it acts at a greater vertical distance from the abutment.

Supposing the vertex of the curve of equilibrium to recede upwards from the crown of the arch, the horizontal thrust will continue to diminish, but its leverage to increase. The bending moment at the crown of the arch may therefore be finite, even when the vertex recedes to an infinite distance. The condition, in fact, then corresponds to that of a girder resting on level abutments and incapable of supplying any horizontal thrust.

On the other hand, if the vertex of the curve descends below the crown of the arch, the bending moment there becomes positive, and tends to increase the curvature of the arch rib. The horizontal thrust is also increased, the weight of the arch remaining the same. When the horizontal thrust is finite, but the weight and rise of the arch are both equal to zero, then the arch becomes a horizontal pillar.

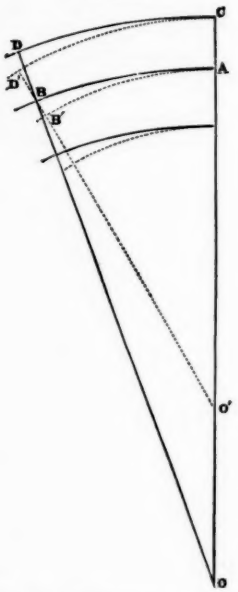
When the springing points of the curve are shifted so that the curve does not pass through the centre of the arching at the abutments, a bending moment, of an amount determined by the alteration of the springing points, exists at the abutments, and the horizontal thrust is also altered.

By thus shifting the position of the vertex, or of the springing points, or both, of the curve of equilibrium, the horizontal thrust, and the transverse stress at the crown and springing may be indefinitely varied, and may be made to satisfy the conditions of a rigid arch with the feet kept from spreading, so that the span is invariable, or of a rigid arch with the ends "fixed," or "*encastré*."

What these conditions are will now be explained; but it is necessary to offer some elementary remarks as to the effect of transverse stress on the curvature of an arch rib.

In Fig. C, if A B be a small portion of the neutral line of an arch rib, its centre of curvature being at O, when it is under transverse strain, the line A B will change to some other position, as A B′, the centre of curvature changing to O′. And a concentric length C D, distant from the neutral line by the length C A, will become curved into C D′, and will be elongated or contracted according as the point C is farther from or nearer to the centre of curvature than the point A.

FIG. C.



The ratio of this change of length C D′ − C D to the primary length C D measures the force exerted by the fibre C D. If a be the reciprocal of the fraction which expresses the extension of the unit of length of the material by a force of 1 ton per sq. in., then $a.\frac{C D' - C D}{C D}$ will be the force exerted by C D considered as having a sectional area of unity. And if the transverse section of the rib be divided into a number of small portions, each having an area $= \Delta A$, A being the total area, and the area of C D be one of these portions, then

$$a.\frac{C D' - C D}{C D}.\Delta A$$

will be the force exerted by C D, considered as having the area ΔA.

But C D—A B : A B : : C A : A O or

$$C D - A B = A B \frac{C A}{A O'},$$

and $C D' - A B' : A B' : : C A : A O'$

or $C D' - A B' = A B' \frac{A C}{A O'}$

and deducing, since $A B = A B'$.

$$C D' - C D = A B \left(\frac{C A}{A O'} - \frac{C A}{A O} \right).$$

Or taking the limit of $\frac{A B}{C D} = 1$,

$$\frac{C D' - C D}{C D} = C A \left(\frac{1}{A O'} - \frac{1}{A O} \right).$$

The force exerted by C D is, therefore, in tons,

$$a \left(\frac{1}{A O'} - \frac{1}{A O} \right) C A \cdot \Delta A,$$

and is thus proportional to the difference between the reciprocals of the radii of curvature A O, A O'.

The moment of this force with respect to the neutral axis is found by multiplying it by C A, or is

$$a \left(\frac{1}{A O'} - \frac{1}{A O} \right) C A^2 \cdot \Delta A.$$

Calling M the moment of the whole sectional area,

$$M = a \left(\frac{1}{A O'} - \frac{1}{A O} \right) \cdot \Sigma C A^2 \cdot \Delta A.$$

The last factor $\Sigma C A \cdot \Delta A$, or the sum of all the small portions of the area, each multiplied by the square of its distance from the neutral axis, is generally represented by I.

Hence

$$M = a I \left(\frac{1}{A O'} - \frac{1}{A O} \right) \quad . \quad . \quad . \quad (1.)$$

But calling t_0 the tension or compression per square inch at the outer surface of the rib, considering C D as this outer surface, and putting $C A = k_0$.

$$\frac{C D' - C D}{C D} = \frac{t_0}{a} k_0 = \left(\frac{1}{A O'} - \frac{1}{A O} \right);$$

and by combining this with (1),

$$M = \frac{t_0}{k_0} \cdot I \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

This moment M, representing the moment of the elastic forces of the rib, is at every point in equilibrium with the moment of the outward forces.

In Fig. D, let $A b = b\,{}_1b = {}_1b\,{}_2b$, etc., each of these being equal to Δs, be a polygon forming the chord lines of a portion of the neutral curve of an arch rib before strain, the centre of curvature being O.

When the rib is strained, the polygon will change into some other form as $A b'\,{}_1b'$, etc., the centre of curvature changing to O'.

If $\Delta s = A b$ subtend an angle θ at the centre O before strain, and an angle θ' at the centre O' after strain, then

$$\theta = \frac{\Delta s}{A O} \qquad \theta' = \frac{\Delta s}{A O'}$$

and

$$\theta' - \theta = \Delta s \left(\frac{1}{A O'} - \frac{1}{A O} \right)$$

$$= \Delta s \frac{M}{a I}$$

by equation (1).

Since lines drawn through the middle parts of these chords, and perpendicular to them, meet in the centre of curvature, the angle $\theta - \theta$ is equal to the angle b' A b', and expresses the change of direction of Δs after the rib has been strained.

The total change of direction of the tangent to the curve of the rib between the points A and B will therefore be the sum of all the values of $\theta' - \theta$ between these limits. Calling this change of angle Θ.

$$\Theta = \Sigma_A^B \frac{1}{a I} M \Delta s.$$

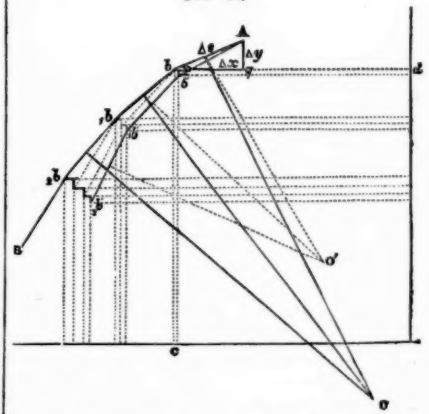
And if, as will be supposed in all the subsequent examples except the last, the section of the rib be uniform throughout the length, the value of I will be constant, and it may be set outside the sign of summation, or

$$\Theta = \frac{1}{a I} \Sigma_A^B M \Delta s.$$

The neutral line of the arch rib having been divided into equal lengths, each equal to Δs, and the value of M being known for each of these portions, Θ is found by summing all these values of M between the limits A and B, and multiplying this sum by

$$\frac{\Delta s}{a I}.$$

FIG D.



If the arch rib be "fixed" at the points A and B, the curve of the rib is

not at liberty to change its direction there by the action of the outward forces, and therefore, in this case $\Theta = 0$, or, if the rib be fixed at the ends, the condition

$$\Sigma_A^B (M) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

must be fulfilled and the curve of equilibrium must be so chosen as to satisfy this condition.

Further, the length of the line $b\ b'$, which measures the change in the position of the end of Δs, is $\Delta s\ (\theta' - \theta)$, or

$$b b' = \Delta s^2 \frac{M}{a I}.$$

Referring the curve to rectangular axes, and calling $b\ q = \Delta x$, $A\ q = \Delta y$, the change $b\ b'$ may be considered as made up of the horizontal change $b\ p$, and the vertical change $b'\ p$.

By similar triangles, $b\ b'$ being small,

$$b p = b b' \frac{\Delta y}{\Delta s}$$

$$= \frac{1}{a I} M \Delta s \Delta y$$

$$b' p = b b' \frac{\Delta x}{\Delta s}$$

$$= \frac{1}{a I} M . \Delta s \Delta x.$$

Therefore if h and v be the horizontal and vertical displacements of the point B, I being supposed constant,

$$h = \frac{1}{a I} \Sigma \Sigma M \Delta s . \Delta y . \quad . \quad . \quad (4.)$$

$$v = \frac{1}{a I} \Sigma \Sigma M \Delta s . \Delta x . \quad . \quad . \quad (5.)$$

the summations being made between the limits A and B.

Fig. D is intended to show the building up of the displacement at B, by the displacements at b, ${}_1b$ ${}_2b$, etc.

Referring to equation (4), the double summation may be made in two ways:

(1.) By forming for each point b the sum of all the values of M from the limit A up to this point, multiplying this sum by the value of Δy at the point, and summing up these products for all the points between A and B.

(2.) Since the sum $\Sigma \Delta y = y = b c$ for each point, the summation may be made by forming the sum $\Sigma (M y)$ or $\Sigma (M . b c)$ between the limits A and B.

The latter, which is that used in Mr. W. Airy's treatise, is the easier one, and is better adapted to the arrangement, here followed, of considering the forces on each element of arc, and the bending moment M, to act at the centre of the elementary arc.

It consists, therefore, of the following process:

Having found the values of M for each part Δs, multiply each value of M by the ordinate $b c$ at the point to which it corresponds, and add all these products together between the limits A and B.

If the feet of the arch rib be kept from spreading, the horizontal displacement is zero, and the curve of equilibrium must satisfy the condition

$$\Sigma (M . b c) = 0 \quad . \quad . \quad . \quad . \quad (6.)$$

between the limits of the ends of the arch rib.

And if the arch rib is also fixed at the abutments, so that not only the span is invariable, but the angle contained between the tangents to the curve at each abutment is also invariable, the conditions (3) and (6) must coexist, or

$$\Sigma (M) = 0$$

$$\Sigma (M . b c) = 0.$$

In this case, the curve of equilibrium generally does not pass either through the crown or the ends of the arch rib, but the vertex and springing points of the curve will require to be altered until the two conditions are satisfied.

These conditions also co-exist if the rib be fixed in direction at one end, and the other end be fixed in position, though not in direction, so that the span remains invariable. The curve of equilibrium will pass through that end of the rib which is only fixed in position, the bending moment being there equal to zero, and the vertex, and springing point of the curve at the other end of the rib, will require to be raised or lowered until the above conditions are satisfied.

Another arrangement, which is virtually a pair of cantilevers meeting in the middle of the span, is where the rib is fixed at the abutments and hinged at the crown. In that case, the curve of equilibrium must pass through the crown, and the springing points be raised so as to satisfy the condition

$$\Sigma (M . b c) = 0.$$

Hitherto the section of the rib has been considered as uniform throughout the whole length. If it is desired to consider the section as changing from point to point, the quantity I which has been taken as constant must be placed under the sign of summa-

tion, or the values of $\frac{M}{I}$ must be used instead of M in satisfying the conditions.

Conditions (3) and (6) will then be replaced by

$$\Sigma\left(\frac{M}{I}\right)=0.$$

$$\Sigma\left(\frac{M}{I}.bc\right)=0.$$

And the value of M for each length Δs must be divided by I before entering it in the sum which is to be made equal to zero between the limits.

To construct a rib with sections at each point proportioned to the stresses, a uniform sectional area may be assumed as a first approximation. The curve of equilibrium being then drawn and the stresses determined, the rib may next be assumed to have sections proportioned to these stresses as a second approximation.

The curve of equilibrium being again drawn, will differ slightly from the previous one, inasmuch as $\frac{M}{I}$ has been used in fixing it instead of M. The stresses being then determined, another approximation to the correct sections will be obtained by making them proportioned to the altered stresses, and will probably be near enough for practical purposes, but the approximation may be carried as far as thought necessary.

Having determined the conditions which the curve of equilibrium must satisfy, it is not difficult to construct the curve after a few trials by the method mentioned at the beginning of this paper. The value of the bending moment or transverse stress at any point thus becomes known.

(To be continued.)

HOMFRAY'S PNEUMATIC TELEGRAPH.

From "Engineering."

A few years since a system of pneumatic telegraph was introduced to public notice by Mr. Wier. Its working was tested in various ways, and, as far as could be then ascertained, it appeared to be a practical success. Its continuous use, however, developed several defects in constructive details, which had to be remedied before it could be relied upon. These defects were ultimately overcome by Messrs. Homfray & Co., who have succeeded in perfecting this useful system of signalling, so that no further fear need be entertained of its failure. The present instrument consists of two essential portions, the communicator and the indicator, which are connected together by a series of metal tubes of $\frac{1}{8}$ in. internal diameter, laid up spirally, and covered with wire in the form of a cable. The communicator consists of a casing about 4 ft. high, and 18 in. in diameter, within which is placed the signalling mechanism. On the top of the instrument is a dial, with the various orders written on plates, and from each of these orders is a tube, which is laid to the corresponding order on the indicator. In the apparatus, as arranged for use in ships, the communicator is fixed on the bridge of the vessel, the indicator being placed in the wheel-house or the engine-room. The signal is given by pressing down a lever, which projects from the indicator under any order it is desired to give. By this action the air is driven into the tube connected with the order, as well as into another tube communicating with a bell attached to the indicator, thereby causing the bell to ring, and the corresponding order to be shown on the dial of the indicating instrument. By locking the lever in a notch, when down, the signal can be maintained for any length of time on the indicator, but on releasing the lever, a shutter falls, and covers the order. The receipt of the order is acknowledged by the engineer or steersman pushing down a handle, which rings a reply bell in the communicator.

The mechanism by which the signals are transmitted, and which is contained in the communicator, consists of a compression cylinder fitted with a piston 6 in. in diameter and having a 2 in. stroke. By depressing the lever, the piston is raised, and the air compressed in the cylinder, at the same time a valve connected with the tube relating to the order under which the lever is depressed is opened. The air from the cylinder is forced into a chamber common to all the valves, but it can only escape through the valve opened by the lever. On releasing the lever a counter-weight draws the piston down, air being admitted to the

cylinder through an aperture in the piston rod—the rod being hollow—which is covered by the stuffing-box as the piston ascends on the next signal being made. In order to prevent the apparatus being affected by variations of temperature, each tube is fitted with a valve by which it is open to the atmosphere when not in use, the action of depressing the lever closing the valve. The bell tube is fitted with a relief valve, which, on the completion of the stroke of the piston, leaves the bell tube open to the atmosphere, by which arrangement it is at all times ready for a fresh order. The pressure is maintained on the signal pipe by means of an air cock, worked by a cam action attached to the lever, and by which the air is shut in the air chamber, and the pressure thus kept on the tube.

The improvements effected by Messrs. Homfray upon the Wier system are very marked; for instance, the power of propelling the air through the tubes in the Wier instrument was obtained by the use of air-tight German silver chambers similar to those used in aneroid barometers, and which were compressed and drawn out by means of a lever and springs. The constant drawing in and out of this thin metal chamber caused the edges to crack, and the air to escape, and rendered the instrument useless. One of the most simple and perfect systems of marine telegraphy was thus in danger of being rejected through the details having been imperfectly worked out. The thin metal air chambers were therefore replaced by the cylinder and piston, and a cut-off valve. In these cylinders and pistons there is nothing to get out of order, and when the packing of the piston wears, it can be readily replaced in the ordinary manner by the engineer on board. In the Wier instrument, the keeping the order exposed to view depended upon the correct fitting of a small leather washer, and it was not unusual for the shutter to fall directly it had risen. In the Homfray apparatus, the shut-off cock, between the cylinder and the various tubes, effectually prevents the shutter falling until the operator releases the lever. The counter-weight on the lower end of the prolonged piston rod is an efficient substitute for the spring in the old system. We recently examined the working of these signalling instruments at Messrs. Homfray's office, and found them well designed and put together. The working parts are mounted on a brass foundation plate, which is carried up, and forms part of the top, the parts being thus fixed perfectly true, with metal to metal. All the pipes and heads are connected with screw unions, which facilitate the operation of putting the instruments together, or of taking them apart, and are, in other respects, a great improvement upon the old solder joints, which often choked so small a tube. The air chambers of the indicator are made of india-rubber, and are much more sensitive and durable than the thin metal chambers of the Wier system. The instruments we examined were working efficiently through 200 ft. of tubing, a distance far greater than will be required on board any ordinary ship.

Our attention was also drawn to Messrs. Homfray's mechanical engine-room and steering telegraph. This apparatus consists also of a communicator and an indicator, connected by means of chains and wires carried on guide rollers. Each of these instruments has a dial on which the various signals or orders are written. The communicator is fitted with a lever which is moved until it stands over the order desired to be given. The act of putting the lever over, rings a bell in the indicator, and at the came time a pointer on the indicator goes over to the order corresponding with that to which the operator at the other end has moved the lever. The action of putting the helm to the position ordered, causes a pointer on the communicator to go over to the order given, and thus the officer on duty sees that his order has been received and executed. Indeed the position of the helm can at all times be seen, as the pointer on the communicator follows each of its movements. These two systems of signalling, especially the pneumatic, appear so well adapted to all the requirements of a ship that they will doubtless come largely into use in that respect as well as in others.

It is claimed that the first investment for the manufacture of pig iron in this country was made in Virginia in 1626. This was followed in 1643 by the establishment of iron works in Braintree and Lynn, in Massachusetts—an enterprise which, after some losses, was successfully prosecuted. Previous to 1721 the manufacture of iron had become very active in New England and Pennsylvania, and no less in Virginia. —*Exchange.*

ON THE UTILIZATION OF BLAST FURNACE SLAG.*

By J. J. BODMER.

From "The Journal of the Iron and Steel Institute."

The quantity of blast furnace slag produced is so enormous, that it would appear a hopeless task to find means for using it all. The average make of slag is about from 1.3 to 1.75 tons per two tons of pig iron, which for the production of about 4½ million tons of pig iron per annum, amounts to no less than from 2¾ million to 3¾ million tons of slag. In the Cleveland district and other parts of the country, the large cubes of slag as they come from the tubs into which it is run, are used for the construction of embankments for foundations, in reclaiming land from the sea, and when broken up, as road metal. For such like purposes the largest quantities can be disposed of; but there is a limit in that direction too, even in the most rapidly growing centres of manufacture, and up to the present time the tipping of the slag, or the carrying away of the same into the sea, appears to be inevitable. A number of patents have been taken out for means and apparatus for the removal of slag from blast furnaces.

It has been tried to run the slag into moulds for ornamental purposes, but the annealing process, which was indispensably connected therewith, proved too costly, and the sundry processes proposed in that direction have been abandoned. In some parts of the Continent the slag has been run into moulds, or simply holes, dug out near the blast furnace, when it was allowed to cool gradually, and then dug out or quarried, and used as building stone. Whilst, however, on the one hand, we do not see how to make use of the whole quantity, or even of any considerable part of the slag produced, and whilst, on the other hand, a number of schemes for turning the slag to account in a manufacturing way have failed, there are nevertheless means by which quantities of that material can be used very profitably, and on that point I beg to offer a few remarks. There are two ways of using the slag for building purposes, and it is in that direction, after all, that any quantities can be disposed of. Firstly, the application of the slag in the shape of sand. The object I have in view, however, is not so much the disposal of any considerable quantity of the slag, but rather its application to purposes for which it is particularly suited, namely, firstly, on account of its chemical properties, for the manufacture of certain classes of cement and cementing compounds; and secondly, in its condition of sand in combination with cementing compounds, or with lime or cements, for the manufacture of artificial stone, for mortar, and for all purposes for which sand is required. There are different means by which the subdivision of slag can be effected. One mode, patented by myself in 1866, consists in the application of two plain rolls running with differential speed. The slag in its viscous condition as it issues from the furnace is made to pass through the said rolls, and drops from the same in the shape of scales of any convenient thickness. From the rolls it may be made to fall on a belt or chain, or into a creeper, which again may discharge itself into trucks.

Such slag, scale, or sand has a peculiar sharpness or grittiness, and being, as a matter of course, free from any of the admixtures which often deteriorate sand for building purposes, it has a special applicability to the manufacture of concrete bricks and other articles. From the shape of scale it is most easily converted into impalpable powder. A mixture of from six to eight parts by weight of slag sand with one part of hydraulic lime, produces a brick, when properly made, which, after two or three weeks, will be less absorbent than a good clay brick by 40 to 50 per cent. The shape of such concrete bricks made under pressure is perfectly accurate, being made in steel moulds, and the color of them can be varied from that of a bright grey sandstone down to a dark iron color. With a systematically arranged set of machinery, such slag bricks can be produced at a small cost.

With two of Bodmer's patent hydraulic presses, 80,000 bricks per week can be produced by 12 hands (6 or 7 men and 5 or 6 boys), engine power 8 to 10 horse power. In winter the fresh bricks are piled up in a shed to prevent freezing before they have set, after which they are piled out into the

* Slag bricks were exhibited at the meeting of the Iron and Steel Institute in London, March, 1872.

open yard; 1,000 of such bricks, London size, weigh three tons.

Although the similarity between Puzzolana or Trass, as seen by comparison of the analyses, is a well known fact, the slag has not been used as a substitute for those cementing materials. The reason, I apprehend, lies in the difficulty, or rather in the costliness of grinding blast furnace slag. If, however, the slag is not allowed to form into hard lumps to begin with, that difficulty falls to the ground, and the rolling process as above described, satisfactorily disposes of that question.

COMPARATIVE ANALYSES.

(Blast Furnace Slag.)

	Cleveland District.			Wales.		Trass.	Puzzolana.	Portland cement.
Silica	36.20	40 75	34.	49.50	45.	57.	44.50	24 31
Alumina	26.	24 47	24 33	15.20	16 42	12.	15.	7.50
Lime	27.	24.50	34.	19.70	26.78	2.60	8.80	60 05
Gypsum	....	....	....	....	....	....	....	1.82
Magnesia	9.	7 17	5 88	3.	0 40	1.	4.70	1.17
Protoxide of iron	1.30	2 05	0 07	8 82	5 20	5.	12.	3 34
Potash	....	....	....	....	0.46	7.	1 40	0 80
Soda	....	....	....	....	....	1.	4.	0 74
Sulphur	0.40	0.65	1 72	1.29	....	....	....	....
Water	..	....	....	....	....	9.40	9.20	....
Protoxide of manganese	....	....	....	....	5.64	....	....	....

From the above figures it is evident that, by the addition of a certain proportion of lime, a good cement can be produced, and at a vastly less cost than any of the Portland cements in the trade. Some slag, when subdivided as described, and ground together with lime to an impalpable powder, forms a strong and reliable cement. In 1869 a patent was granted to me for that process; and as far back as 1866 I made samples of cement from Ponty-pool cold blast furnace slag and Abersychan lime, in the proportion of seven parts by weight of the former to one part of lime.

The following are the results of some of the tests as compared with Portland Cements:

Figures taken from experiments made on the strength of Portland cement, by Mr. John Grant, M. I. C. E., 1866.			SLAG CEMENT. Experiments made by J. J. Bodmer, 1866.		
Weight of cement per bushel.	Age after gauging.	Tensile strain sustained per 1 square inch.	One part by weight of lime with 7 parts of slag.	Age after gauging.	Tensile strain per 1 square inch.
lbs.		lbs.			
106.7	7 days	157.6			
107.6	"	156.56			
111.75	"	201.63			
114.15	"	269.78		7 days	271.22
119.04	"	248.03			
119.07	"	305.89			
121.0	"	409 77			
"	14 days	472.26			
"	28 days	499.51		1 month	472.18
"	2 months	522.44			
"	3 months	558.62			

Now, whilst to a great extent the composition of Portland cement can be regulated, the blast furnace slag, from well-known causes, alters materially; and unless a furnace was worked with the same charge, and the slag was used at the same point of grayness uniformly, a quality of cement equally reliable at all times, could not be

produced. But, on the other hand, it is certain that an energetic hydraulic compound can be made of all but the worst black slag. The latter sets also, but slower, and without attaining the same degree of hardness as the cement made from gray iron slag. According to the purposes for which the material is intended, the slag cement can be varied from the composition and strength of Portland cement, down to that of a simple hydraulic lime. When used in the manufacture of bricks, the setting time and the ultimate absorption of the bricks are in proportion to the quantity and quality of the slag cement used. For instance, from a slag cement of seven parts of slag and one lime worked together, with an equal weight of slag sand, bricks are produced which, after a short time, are practically non-absorbent. The quantity of the slag sand used in the manufacture of the brick can be increased in proportion to the quantity of lime used in the manufacture of the slag cement, up to one part of such cement to seven parts of slag sand. We have, therefore, the means of manufacturing bricks from the cheapest possible materials, and varying at will in quality and color. The new and interesting mode of dealing with sewage precipitates, by Major-General H. Y. D. Scott, C. B., will enable all large towns to convert the sewage into a hydraulic lime or cement, at a cost of something like 9s. or 10s. a ton; and when that process is fairly introduced, two descriptions of material (sewage and slag), hitherto difficult of disposal, will be manufactured into building material of excellent quality, and for which there will be at all times a great demand. The bricks exhibited at the aforesaid meeting were in part made of slag cement and slag in the condition of sand, and in part of slag cement and ordinary sand.

ON THE COMPOSITION OF ANCIENT CEMENTS AND ROSENDALE CEMENTS.*

The cements commonly used in New York and elsewhere for ordinary constructions as well as for large engineering works, have frequently elicited the interest of inquirers into their nature and properties.

Among the best descriptions of the qualities of these cements we may cite General Gillmore's work on the subject, in which we find a list of valuable experiments which set forth the properties of various cements, and also a table showing the chemical composition of a number of cement stones from which our cements are made.

These experiments and tables do not, however, contain the chemical analysis of the cements themselves, upon which so much depends.

The chemical analysis of several of the Rosendale cements has lately engaged my attention, but before setting forth the results obtained I will recall briefly the history of our modern knowledge of cement.

The monuments of Egypt present one of the oldest examples of the use of lime for constructions. The mortar which joins the stone of the Pyramid of Cheops is precisely similar to modern mortars made of sand and lime. In limiting the use of mortar to filling narrow joints which separate immense blocks, and thereby reducing almost to insignificance the part which it had to play, the Egyptians seemed to forestall the influence of a dry and burning climate. Time has justified their prudence in this respect, for the works erected on the banks of the Nile by the Romans, made of small materials and presenting many joints, have left but faint traces, whilst some Egyptian temples still present themselves intact to our admiration.

Unqualified praise has often been given to the excellence of Roman mortar, and the belief is sometimes expressed that all we can hope to do is to regain the secret of making mortar once possessed by the Romans. It is a common remark that "Roman mortar has lasted for eighteen centuries, whilst a number of modern buildings are in a deplorable state of preservation."

To make a fair comparison, we should, however, only cite similar constructions, and then we are comforted by these words of Pliny: "The cause which makes so many houses fall in Rome, resides in the bad quality of the cement."

The knowledge of the properties of lime descended from Egypt to Greece, where the exigencies of the climate and the ingenuity of the people brought forth many of its uses, unknown to Egypt.

* A paper read before the Am. Society of Civil Engineers, by Arthur Beckwith, C. E.

Subsequently Greek colonies imported and popularized their processes in Italy; and Roman architects, like Vitruvius, cite the names of Greek authors on the art of construction. Their names alone have come down to us, but Vitruvius had full access to them, and in our inquiry after the knowledge of mortar possessed by the Romans, it is to him that we must refer for information. Indeed he has left us a detailed table of precepts used by the builders of Greece and Rome, which do not justify our unreserved admiration; everything relating to lime, sand, and pozzolana is clearly treated therein.

We may safely affirm, with Vitruvius, that the Romans made use of the lime, sand, and materials of the countries where they built; that they considered the best lime to be produced from hard and pure marble, *i. e.*, the fattest lime known; that in Italy they mixed it with pozzolana when used for hydraulic purposes, and that out of Italy they replaced the pozzolana from Vesuvius, by powdered brick or tile.

Roman mortars, when examined to-day, are found to bear a distinct resemblance to each other; they may be recognized by the presence of coarse sand mixed with gravel; lumps of lime are so often to be met with, that incomplete slaking will alone account for them. Mortars laid in damp spots for cisterns and pavements, were composed of bricks in small fragments mixed with fat lime; this concrete required to be compacted by pounding and left to dry—the surface was then scraped, polished, and painted—evidently to prevent the dissolution of lime by water.

It will be seen by this that what we term hydraulic lime, and also the modern product of cement, were unknown to the Romans.

It is important to refute the belief that methods may have been known to them of which we have lost the secret. When the decay of arts followed upon the downfall of the Roman Empire, houses nevertheless continued to be built, and the familiar processes under the eye of the workman must have been transmitted from father to son. So true is this that to-day Italian masons, who certainly have not read Vitruvius, make coatings for cisterns and concrete floors in the very same manner as may still be seen in the ancient ruins of Rome.

Neither is it true that Roman mortar is uniformly good. Its strength of cohesion varies in different examples from 35 and 85 lbs. per sq. in. to 100 and 160 lbs., or as much as 500 per cent.

In the middle ages a volcanic conglomerate from the banks of the Rhine, named trass, was substituted forthe pozzolana of Italy, and mortar was made of fat lime, mixed with trass, to render it hydraulic.

Many castles erected during that period stand well to-day; the well-known castle of the Bastile, erected in 1369—83, which after withstanding a siege required the use of powder for its destruction in 1789, was found to be extremely solid even in the interior walls.

It would seem, then, that the secret of the Romans was known also in those times, and could have been lost only at the Renaissance, when least of all such a supposition is probable.

At what period were first used certain limestones, having the property of producing a lime which will harden under water, is not precisely known; the first use of cement stone is equally obscure.

In 1796 Messrs. Parker & Wyatts began to manufacture from egg-shaped limestones found near London, a product known later as *Roman Cement*, and which was soon received with great favor throughout Europe; but neither the producers nor the consumers offered any explanation of its merits.

Not until 1818 and the following years was the true explanation given of the hydraulic properties of limes and cements, when Vicat published his discoveries.

Before that, in 1756, when Smeaton was preparing the arduous and bold construction of the Eddystone Lighthouse, this celebrated engineer examined with scrupulous attention the natural hydraulic lime of Aberthaw. Treated by acids it left a residue "which appeared to be a bluish clay, weighing about $\frac{1}{8}$ of the total weight of the stone."

In 1786, Saussure attributed the hydraulic properties of some limes of Savoy to the combined influence of manganese, quartz, and even clay; but he left his opinions in the mere state of conjectures.

Finally, Descostils, in 1813, having discovered a considerable proportion of finely divided silica in the lime of Senonches, attributed the well-known hydraulicity of that lime to the silica it contained.

But the conjectures of Smeaton, of Saussure, and of Descostils were vague; they rested upon no proofs, and found no applications in practice.

The discoveries of Vicat attained their immediate object, for in a short time artificial hydraulic lime of excellent quality was manufactured on a large scale under his direction, and a few years later he indicated as many as 400 quarries in France where hydraulic limestones were to be found.

Moreover, the mortar made from his hydraulic lime equalled in hardness at the end of eighteen months the hardest ancient Roman mortars.

It is unnecessary to recall the evidence by which Vicat demonstrated—by analysis and by synthesis—his great discoveries. No one questions to-day the fundamental truth, that the properties of hydraulic limes depend upon the proportion of clay disseminated throughout its tissue, and that clay by being calcined acquires the property, like pozzolana or trass, of rendering fat limes hydraulic, when thoroughly diffused throughout their mass.

The labors of Vicat and Berthier have led to the following classification of limes and cements, and consequently of limestones and cement stones:

Table of Classification of Limes and Cements.

Proportion of clay in the limestone.	Proportion of clay in the product.	Class of lime or cement.
Less than 10 per cent.	Or less than 17 per cent.	Fat and non-hydraulic limes.
From 10 to 15 "	From 17 to 24 "	Slightly hydraulic limes.
" 15 to 17 "	" 24 to 27 "	Hydraulic limes.
" 17 to 20 "	" 27 to 30 "	Eminently hydraulic limes.
" 20 to 23 "	" 30 to 34 "	Limit of hydraulic limes.
" 23 to 30 "	" 34 to 43 "	Beginning of cements.
" 36 per cent.	" 50 per cent.	Good hydraulic cements.
" 40 per cent	" 54 per cent.	Hydraulic cements of diminishing value.
" 60 to 90 per cent.	" 73 to 94 per cent.	Pozzolanas.

A point which bears directly upon our subject is the fact of the existence of a limit for the proportion of clay, at either end of the scale of cements. The transition from the properties of hydraulic lime to those of cement is not gradual, but sudden. Thus a limestone containing 20 per cent. of clay will produce an eminently hydraulic lime, but if we increase this proportion to 23 per cent., it is neither a hydraulic lime nor a tolerable cement that we have, but a worthless product, which if submerged will remain for days and even weeks without giving any sign of slaking, and then crumble away insensibly without effervescence; or if pulverized and tempered like plaster, will give an appearance of setting, but crack and turn into mud when submerged.

These products, which may be called the intermediate limes, are found on an average between 20 and 23 of clay for 100 of limestone; but these numbers are not absolute, for some limestones containing 21 and 23 per cent. of clay make both good hydraulic lime and cement, and also the former when underburnt give very irregular results, forming sometimes a cement and at others a worthless compound.

In the same way there is a superior limit to the proportion of clay in cement, which when surpassed gives a poor cement. The exact position of this superior limit is not entirely agreed upon. It is placed at 36 per cent. and sometimes 40 per cent. by Vicat, and at 40 to 46 per cent. by Berthier.

The composition of the layers forming the quarries from which the Rosendale cements are taken is extremely variable, the proportion of clay ranging from 15 per cent. to 47 per cent. Some of these layers contain the right proportion of clay for good hydraulic limes, and for cements, while others contain the proportions which correspond to the intermediate limes and the superior limit of cements. The separate layers are not entirely uniform in their composition, and, like all beds of limestone, those situated near the surface lose a portion of their carbonic acid by the alternate action of heat and moisture.

Therefore, if the stones obtained from the different layers be mixed according to color and physical appearance, as is sometimes practised, and without a due regard to the exact chemical composition of each, it is obvious that uniform and good results are not likely to be obtained.

I am unable to give at present the result of the analysis of more than four of the different brands of Rosendale cement which I have examined, and the labor being incomplete, I refrain for the present from naming the brands which have been analyzed.

The following are the results:

Analysis of Cement No. 1.

Water	1.2 per cent.		
Carbonic acid	traces.		
Silica	30.7	per cent.,	(or as 43.6 per cent. of clay to 56.4 per cent. of lime and magnesia.
Alumina and sesquioxide of iron	12.0		
Lime	42.6	per cent.,	
Magnesia	12.8		
Total	99.3		

Analysis of Cement No. 2.

Water	0.2 per cent.		
Carbonic acid	traces.		
Silica	33.	per cent.,	(or as 46 per cent. of clay to 54 per cent. of lime and magnesia.
Alumina and sesquioxide of iron	13.		
Lime	33.	per cent.,	
Magnesia	20.		
Total	99.2		

Analysis of Cement No 3.

Water	0.5 per cent.		
Carbonic acid	traces.		
Silica	27.	per cent.,	(or as 37 per cent. of clay to 63 per cent. of lime and magnesia
Alumina and sesquioxide of iron	10.		
Lime	50.3	per cent.,	
Magnesia	12.		
Total	99 8		

Analysis of Cement No. 4.

Water	0.2 per cent.		
Carbonic acid	traces.		
Silica	31.6	per cent.,	(or as 40 per cent. of clay to 60 per cent of lime and magnesia.
Alumina and sesquioxide of iron	7 8		
Lime and magnesia	60.	per cent.,	
Total	99 6		

These results show that the Rosendale cements above examined contain a proportion of clay which approaches, in some cases, to the proportion indicated by Vicat as forming the best cement, and in others to a proportion nearer the beginning of the scale of cements.

A point worthy of notice is, that if we compare these cements to the English and French cements, the one marked No. 3 contains nearly the same proportion of clay as the French Portland; No. 4 contains the same as the cement of Vassy; Nos. 1 and 2 contain more clay, although nearer the proportions named by Vicat for the best cements, and all contain more magnesia than is common to European cements.

The cements examined also contain traces of alkalies and chlorides. One contained $\frac{7}{1000}$ of sulphate of lime, which is not to be considered injurious, as it does not exceed three per cent.

The large proportion of magnesia in these cements is remarkable. Chemists are not wholly agreed upon the effects of magnesia in the presence of lime.

Magnesia in the presence of silica and alumina is known to form crystallizations which resist the action of sea water better than lime, and Vicat remarks that the presence of magnesia exalts the quality of cement for marine uses.

On the other hand, it is equally certain that the silicate of magnesia crystallizes slower than the silicate of lime, and Rigot asserts that the consequence of the presence of magnesia is disaggregation, or at least inferior hardness.

In the presence of these conflicting opinions the true influence of magnesia remains a subject for investigation.

Having but recently analyzed various American limes and cements, I am not able to present comprehensive or complete results, and my object in introducing the subject at this stage is to call the attention and invite the labor of others, in completing the studies required for the uniform production of the best quality of hydraulic limes and cements. But my inquiries have gone far enough to convince me that standard cements will not result from experimental mixtures, not guided by selections based upon accurate analysis.

I conclude with the following analysis of Rockland lump lime:

Water and carbonic acid	traces.		
Silica	5.6	per cent., or 7.8 per cent. clay.	
Alumina and sesquioxide of iron	2 2		
Lime	87.6	per cent., or 91.9 per cent. lime and magnesia.	
Magnesia	4.3		
Total	99.7		

SMOKE PREVENTION.

From "The Engineer."

The last number of the "Journal of the Royal United Service Institution" contains a very interesting paper "On the Economy of Fuel in Ships of War," by Mr. T. Symes Prideaux. Mr. Prideaux has for many years, as most of our readers are, no doubt, aware, labored energetically to secure efficient combustion in steam boiler furnaces; and although the paper we have just named does refer slightly to other points connected with economy of fuel, it is mainly devoted to an investigation of the laws of combustion in steam boiler furnaces, and the means to be adopted in rendering combustion as complete as possible. The subject is one of infinite importance to every employer of steam power, and it is to be regretted that the "Journal of the Royal United Service Institution" is not so generally accessible as is to be desired. We shall endeavor to put Mr. Prideaux's propositions before our readers in as condensed a form as possible.

Mr. Prideaux, after a few general statements, proceeds to explain the laws of combustion. We have no exception to take to the manner in which he does this; still we think that the whole gist of the subject may be put into a somewhat more compact form than that which he has adopted. He refers, as is usual, to the atomic composition of gases, and speaks of volumes of oxygen, carbonic oxide, etc., in a way which, albeit quite satisfactory to the chemist—or, at least, to those possessing some chemical knowledge—does not appeal very directly to ordinary steam users. We shall put the facts in our own way: When a pound of carbon is completely burned, it liberates 14,500 units of heat; in other words, 1 lb. of carbon so burned liberates heat enough to convert 15 lbs. of water into steam. In practice it is quite impossible to burn the 80 per cent. or so of carbon which coal contains, at one operation. When the furnace is charged with fresh cold fuel, that fuel will not burst into flame all at once—on the contrary, it undergoes a species of distillation. Ordinary coal may be regarded as containing 80 per cent. of carbon and 5 or 6 per cent. of hydrogen in chemical combination with the carbon, and at low temperatures—less than 800 deg.—the hydrogen escapes in combination with carbon as carburetted hydrogen; but hydrogen at a high temperature unites with eight times its weight of oxygen; the result is, that the combustion of 1 lb. of hydrogen liberates about 60,000 heat units, or four times as much as a pound of carbon. Unless 8 lbs. at least of oxygen are supplied to each pound of hydrogen, the carburetted hydrogen gas does not burn at all, however high the temperature,, but flies up the chimney with a resulting waste equal to about 15 per cent. of the whole fuel. Turning now to the carbon, we find that, if enough oxygen be supplied, that is to say $2\frac{2}{3}$ lbs., or 12 lbs. of air per pound of carbon, and if the temperature be sufficiently high, we have complete combination, the resulting product of combustion being $3\frac{2}{3}$ lbs. of carbonic acid, or, in modern chemical nomenclature, carbonic anhydrite. But this perfect combination can never be secured at once. A portion of carbon next the firebars unites at once with the required quantity of oxygen, and the resulting carbonic acid, in ascending through the green fuel above it, dissolves the carbon. The $3\frac{2}{3}$ lbs. of carbonic acid, resulting from the complete combustion of each pound of carbon next the grate-bars, dissolve another pound of carbon, and become converted into carbonic oxide, sacrificing, in doing so, 5,700 units of heat. Each pound of carbonic oxide then represents 14,500 units of heat due to the pound of carbon dissolved, and 5,700 units of heat absorbed in effecting the solution, or 20,200 units of heat in all. To recover this we must supply each pound of carbonic oxide with $2\frac{2}{3}$ lbs. of oxygen when it burns with a blue flame and gives out all its heat. It will be seen from this that, by wasting the carburetted hydrogen and the carbonic oxide, we can sacrifice, in round numbers, about two-thirds of all the heat generated. In practice few furnaces are so badly constructed that this result always takes place; but it is also true that, under ordinary conditions, most furnaces send a great deal of carburetted hydrogen and carbonic oxide up the chimney. The remedy is, of course, to supply sufficient air; but from the very nature of the case it appears to be impossible to do this through the bars. The larger the supply through them the larger will be the quantity of carbonic acid produced per minute, and the

greater the quantity of carbon dissolved and carried off, as carbonic oxide. Air must be admitted above the fire as well as through the bars, in order that a sufficient quantity of the *free* oxygen may be supplied to combine with the carbonic oxide and reduce it to carbonic acid. The late Mr. C. Wye Williams, and many others with him, held that it was proper to admit air continuously above the bars to secure complete combustion. In a certain sense Mr. Williams was right, but practically he was wrong; and although complete combustion may be effected with perforated doors, it is well known to every engineer that, as a result of the free admission of air over the fire, the steaming powers of a boiler are reduced, although the economic efficiency of the fuel is to some extent increased. The reason is this: The air admitted carries off heat with it which ought to go to the water, the temperature in the furnace and flues is reduced, and it is, indeed, quite possible to admit air enough to defeat the object in view, because the temperature of the gases may be so lowered thereby that they will not burn. The great demand for air above the bars occurs just after firing. In the first place, because it is only during the few minutes after firing that carburetted hydrogen is produced; and, in the second place, because just then the influx of air through the bars is reduced to a minimum in consequence of the increased thickness of the bed of fuel through which it has to force its way. After the fire has burned clear, we are done with the hydrogen, and as the fire thins, sufficient air will find its way through the bars to secure the combustion of most of the carbonic oxide. Under the best circumstances it is probable, however, that a considerable portion of this gas escapes unburned; but it is better to submit to this loss than to incur the far greater evil caused by admitting air freely at all times above the bars.

In all that we have just written we have expressed opinions with which Mr. Prideaux coincides, although we have placed the statement of facts in a different form from that adopted by him. We have now to explain how Mr. Prideaux applies his knowledge in practice. It is well known that a great number of inventors have devised schemes for admitting air above the burning fuel for a limited period, varying, say, between 1 and 5 min. after firing. The great difficulty to be contended with is, the inherent roughness of the conditions under which stoking is effected. It will not do to leave the regulation of the air admission to the stoker, as has been abundantly proved in practice; nor can any delicate combination of automatic mechanism be trusted to remain in order for any time in the dust and heat of a stokehole. For about twenty years Mr. Prideaux has labored to produce some device which will get over these difficulties, and we think we can say, after a personal and careful examination of his apparatus, that he has been in the main successful. A portion of his paper in the "Journal of the Royal United Service Institution" is devoted to a description of this apparatus, which we shall illustrate in an early impression. Its principle may be very easily rendered intelligible, however, without drawings. To the inside of the fire-door is fitted a perforated false door. The space of a couple of inches between the two doors is closed at the bottom and two sides. The top is fitted with a light flap of thin iron. When this flap is raised air rushes down between the doors and through the perforations in the inner door into the furnace. When the flap is shut down no air can enter the furnace, save between the fire-bars. The door is fitted with the simplest conceivable device, by which, whenever it is fully opened—as for firing—the flap is thrown up and air admitted. In order to retard the falling of the flap, a little mercury cataract is fixed on top of the door, and the time during which air is admitted is determined by the rate at which the mercury can escape from the under to the upper side of a cup. As this cup fills, the air-admission flap sinks and cuts off the supply of air. There is nothing about this apparatus to get out of order, and we are unable to see how anything can be simpler or better suited to the object in view. The apparatus has been tried on a very large scale in the steamship Republic, with results of the most satisfactory character, as we have already stated.*

We must refer our readers for a detailed statement of the results he has obtained in other cases to Mr. Prideaux's paper. It will suffice to state here that we believe he has solved a difficult problem in a way, upon the whole, satisfactory. We know, by personal observation, that he has completely succeeded in preventing smoke un-

* *Vide* "The Engineer" for October 11th and November 1st.

der difficult circumstances, which is, perhaps, no remarkable feat; but he has done more than this, for he has succeeded in effecting a considerable saving in fuel as well without reducing the evaporative efficiency of the boiler. This is a point of very considerable importance, as we have shown. Mr. Prideaux has brought a thorough knowledge of his subject to bear in working out the details of his invention, and this is, no doubt, the reason why he has obtained satisfactory results from it.

THE BESSEMER SALOON STEAMBOAT.

From "Naval Science."

No engineering question has assumed greater importance of late years than what is known as the channel problem. Numerous schemes, some of them marvels of ingenuity, have been proposed from time to time for the purpose of diminishing the misery and discomfort caused by a journey across the Channel, but none have yet ripened into execution. It has been generally assumed that the present steamers are as good as can be obtained while the harbor accommodation on the French side remains what it is, and that no substantial improvement can be made upon them, except in connection with the difficult and tedious undertaking of providing deep water harbors of a special character. Many eminent engineers have considered, however, that if deep water harbors could be obtained, and an efficient class of ships employed, we ought not to rest satisfied even with that; and they have urged with great persistency that the idea of ships should be given up altogether, and that some more direct communication should be effected between England and the Continent, either by tunnel, bridge, or submarine tube.

We shall not attempt to discuss the abstract merits of the various schemes that have been put forward, or to argue that the sea passage is preferable to any other mode of transit that could be devised. It is sufficient for us to know that, whatever may be its advantages or disadvantages, we shall have to put up with it for some years to come. Whether ships are to be superseded hereafter by some more ambitious scheme or not, we must trust to them for the present, and it only remains for us to construct ships of an improved type that shall be specially adapted to meet the various conditions of the case.

In connection with the subject of the ships, that of the harbors forces itself into notice. As we have already intimated, it is generally assumed that the ships now in use are as efficient as the state of the harbors they have to frequent will admit, and there is a distrust in many persons' minds of any attempt to improve the steamers without, at the same time, either deepening and enlarging the present harbors or constructing new ones. There is no sufficient reason, however, for supposing these two questions to be inextricably bound up together. Certainly better harbors are extremely desirable, and would be of great advantage in removing the embarrassment caused by the limitation of the steamers to a shallow draft of water, and also in the greater facilities they could be made to afford for embarking and disembarking passengers and their luggage; but they are not indispensable.

These considerations have led to plans being prepared by Mr. Bessemer and Mr. Reed, for a ship that will, in their opinion, meet in the best and readiest way this great public want. The ships they propose will reduce the disagreeable features of the passage to a minimum. They will be very swift, so as to make the time spent on the sea as short as possible; they will possess qualities which will insure them great steadiness among the waves they will meet; and they will be provided with everything that can contribute to the comfort and convenience of the passengers. They will find the necessary accommodation in the present harbors, and can be built and got to work in a few months. It therefore appears very unnecessary and unpractical to complicate the whole question, and cause great delay, by considering it solely with reference to improved harbors, especially as, when deep water harbors are made on the French coast, these steamers will be admirably adapted to use them.

The vessels are double-ended, and are propelled by four large paddle-wheels, two at each side. The ends are kept low for the purpose of reducing the motions pro-

duced by the action of the wind and of the sea, and the middle portion is made sufficiently high to enable them to steam at a high speed against the worst seas they will have to meet. A rudder is fitted at each end, with means of locking, so that the ship will be able to steam in either direction and will not require to be turned round in harbor. The great peculiarity, however, of these ships is that each will contain a large saloon, designed by Mr. Bessemer, suspended in the middle of the ship in such a way that it can be moved about a longitudinal axis parallel to the keel. The motion of this saloon, which would be set up when the vessel rolled if left free to move, will be governed by an hydraulic apparatus and will be completely under the control of one man, whose duty it will be to keep the floor of the saloon, under all circumstances, in a line with a spirit-level. Each steamer will be 350 ft. long, 40 ft. wide along the deck beam, and 65 ft. wide across the paddle-boxes. She will draw 7 ft. 6 in. of water, the same as the present steamers, and will be propelled at a speed of 20 miles per hour, by two pairs of engines of the collective power of 4,600 horses. The centres of the two pairs of paddle-shafts will be 106 feet apart.

The passenger accommodation will consist of the Bessemer saloon, which is 70 ft. long, 35 ft. wide, and 20 ft. high ; a fixed cabin at one end between decks, 52 ft. long; and a line of small cabins on each side of the ship between the paddle-boxes, that will occupy a total length of 150 ft., and include a refreshment cabin, smoking cabin, lavatories, and small deck cabins. The luggage will be stowed in the hold at the opposite end of the ship to the passenger cabins. The Bessemer saloon will form by far the finest cabin that has ever been fitted in a ship. Its great size and height will enable it to be completely ventilated, and will prevent passengers who use it from feeling the unpleasant sensations usually connected with going below. The free air of this spacious and well-ventilated apartment will be quite different from that of a cabin between decks, and will render it unnecessary for ladies and delicate persons to remain in the worst weather on deck rather than accept shelter in it. But one of the greatest advantages of this saloon is that whatever motion the ship may take from the waves—and this, from the adaptation of her form to passivity among Channel waves, will be slight—the saloon will be practically free from it. It is in the middle of the ship, as regards length and breadth ; and the axis of rotation is at a height where there is least motion, so that as regards its position it is one in which the vertical and lateral motions produced in every part of the ship by the pitching and rolling will be so small as to be inappreciable. The cabin will also have no sensible pitching motion, for the form of the vessel is such as to make it impossible for the sea of the Straits of Dover to raise the ends very considerably, and even the small effect produced at the ends of the ship will be reduced to one-seventh at the extremities of the cabin. The rolling motion of the ship on the intended service can not be very great, for reasons to which we shall presently direct attention, but such as it is it will not be communicated to the cabin, for the perfect action of Mr. Bessemer's hydraulic apparatus is an established certainty, and not a matter of speculation, and it will always insure the floor being kept level.

In addition to the saloon being thus made practically independent of the irregular movements of the ship as a whole, it will also be made free from sharing in the tremulous motions set up by the working of the engines or the shocks of waves against the side. This will be effected by resting the supports of the saloon upon massive beds of india-rubber, and thus making it impossible for any vibratory motion to be transmitted from the ship to the saloon. The floor will also be freed from vibration by special means.

There have been plenty of persons ready to offer their opinions upon, and explain their objections to, the essential features of this vessel; but we have not yet seen any one positive fault exposed. All that the arguments we have yet seen could possibly prove, if they were admissible, is that we shall not not be able to attain perfection in these ships. As the suspended cabin is the most novel feature in connection with them, discussion naturally turns upon it, and all that the objectors who have yet come forward try to prove is that we shall not be able to take away all (save the onward) motion from the saloon. Nobody has yet shown that the form of the ship, especially at the ends, and the position of the cabin in the middle of the ship, are not such as will reduce the pitching motion of the saloon to the smallest amount, and make it so small

as to be inappreciable in the waves of the Dover Straits. Even Admiral Elliot, in his letters to the "Times," admits that the form of the extremities of the ship will have the effect of diminishing the pitching; but he contends that the speed will suffer in consequence by reason of the quantity of water that will wash over the deck when she is being driven at full speed in bad weather. He assumes that the speed will have to be reduced in order to obviate this; but we certainly fail to see what would be gained by keeping water off this low deck, which is expected to be frequently under water; or what harm can be done by driving it under the comparatively small waves of the Dover Straits, and allowing the crests to break against the end of the upper deck, which is adapted for clearing the water, and throwing it on one side, the same as if it actually formed the bow. Admiral Elliot would not object to a bow 12½ ft. above the water if it were at the very end of the ship, where it would have to force its way through solid waves, and we should like to know why he thinks it must fail to do its work because it is shifted back 48 ft., where it can only be washed by broken water that has passed over the low deck in front of it.

It has also been generally admitted, as far as we have seen, that the saloon may be prevented from rolling with the ship, and that there is nothing in the character of the ship to make her likely to roll heavily in the Dover Channel. Her size and form, and the great powers of resistance to rolling she will possess, will insure her great steadiness among the kind of seas peculiar to that part of the Channel. The resistance her paddle-wheels will offer to rolling, and the great speed at which she will be driven, will all conduce to steadiness, and, in addition, she will have bilge pieces 3 ft. wide and nearly 100 ft. long placed between the two paddle-wheels. Such rolling as will nevertheless be set up in the ship will be prevented by Mr. Bessemer's apparatus from communicating itself to the saloon, and it may be safely assumed that the saloon will not be appreciably affected by the rolling motion. It has also not been denied, as far as we are aware, that any vibratory motion existing in the ship may be prevented from being felt in the saloon by the means proposed. It has, therefore, not even been disputed by objectors that we can, by means of the Bessemer saloon in connection with a ship of this character, give the channel passengers relief from three great causes of distress—the pitching and rolling motions of the ship, and the continual vibration and noise peculiar to a steamer. One would naturally think that if this is the case we have much cause for congratulation, and have at least removed some of the most objectionable features of a sea passage.

But we are gravely told that this is not the case; it is not, it is now said, the pitching and rolling of a ship that cause sea-sickness, so much as certain other movements described as lateral, vertical, and onward. We will, however, with the permission of our readers, eliminate the onward movement at once from among the causes of sea-sickness. As Mr. Bessemer has pointed out in his letter to the "Times" of the 18th November, people are constantly travelling in railway carriages at speeds far greater than any yet attained by a ship, without feeling any very unpleasant effects from the onward progress.

The only two movements left, therefore, as causes of sea-sickness, are the lateral and vertical motions. We cannot think that merely lateral motion could produce very disagreeable effects, even if continued for some time, at any rate such effects as may be compared with the results of ordinary rolling and pitching. We are therefore inclined to put down lateral motion as a very minor cause, if it is a cause at all, of sea-sickness; but even if it were, the lateral motion of the Bessemer saloon in this ship will always be extremely small. The axis of the saloon is placed at a height where the lateral motion produced by rolling is least, so that the whole of the passengers in the saloon will have the benefit of a minimum of it.

In ocean steamers great lateral movements (and also vertical ones, to which we shall presently refer) are produced in a ship when she is among large waves, except when she is cutting square across them, on account of her partaking of some of the motion of the wave particles, and being moved to and fro, and up and down, upon the slopes of the waves; but this cause will never operate upon this ship, because she will never, between Dover and Calais, fall in with a regular series of waves sufficiently large to produce it. She may be rolled a little from side to side by some Channel waves, but her size is too great as compared with them, to make it possible for

her to be swayed laterally from side to side as though she formed part of single waves, especially considering the great speed at which she will travel. The only appreciable cause of this lateral motion will, therefore, be that due to the movement of the axis of the saloon when the ship is rolling; and, as we have already stated, this is placed at such a height in the ship as will reduce this movement to the least possible amount.

We now come to the vertical motion. Objectors say that this is the most fatal cause of sea-sickness of all; and Admiral Elliot gives a very graphic description of his experience, when lying in a cot, of the effects of the lateral and vertical motions. There is no analogy, however, between the two cases. He deals with the case of a cot slung in an ordinary manner, at an usual place, in a ship at sea, where she meets with waves that are very large in proportion to such ships as he has served in. Therefore his ship was liable to great bodily rising and falling, and this was aggravated by the vertical components of the rolling and pitching movements. In the case of the Bessemer vessel, on her intended service, we have a large vessel floating in comparatively small waves, with all the motions, thus already small, made still smaller by special features in the design, and (so far as the saloon is concerned) with the remaining portion of the rolling and pitching motions practically annihilated, or very nearly so. What resemblance is there between the two cases? Some bodily rising and falling there will no doubt be, but it will be comparatively small, especially when the ship is at full speed. But even if there were grounds for expecting very much larger vertical motion, that would, in our judgment, enhance rather than diminish the desirability of abolishing as far as possible the remaining motions, and furnish no reason whatever for retaining much avoidable misery because some unavoidable discomfort may still remain.

It will be seen from the foregoing remarks that every thing that promises to secure the passengers immunity from sea-sickness has been done in these ships. Rolling, pitching, and vibratory motions will not be inconveniently felt in the saloon; and any lateral or vertical movements that may be set up in the ship (a ship, be it remembered, designed with especial reference to prevention of such motions) will only be communicated to the saloon to the extent to which they exist at that part of the ship where they are least.

We would also refer to the objection that has been raised against these ships on the ground of their length. It has been said this will make it difficult to take them in and out of the present narrow harbors with safety, because, when one end is between the piers and sheltered from the wind, the other will be liable to be blown round on to the pier. In point of fact, however, the vessels are not long vessels when viewed with reference to the wind's action. The only part upon which the wind can act is the 252 ft. in the middle of the length through which the upper deck extends. It can have no power on the 48 ft. at each end beyond this; but, on the other hand, this 48 ft. will resist powerfully, being moved sideways through the water, so that the wind's action cannot possibly be felt on these ships as much as it would on an ordinary ship 252 ft. long. It is difficult to conceive, considering the great resistance the ends will afford to being moved out of the direct line of motion, how the wind can have more power over these ships than it has over the present ones.

With regard to the double paddle-wheels on each side, a few timid doubts have been expressed as to the effect this arrangement will have upon the speed, but nothing has been advanced to show that the after paddle-wheel will be so inefficient as to make the expected speed doubtful. The fact that it will have to make more revolutions than the one before it, in order to transmit the power of the engines to the water, and by reaction to the ship, is no serious matter, and does not justify any doubts upon the practicability of obtaining the speed.

The substitution of steamers of this type for the present ones will be a great boon to numerous travellers, even according to the worst estimate that has been put upon their merits. If the saloon could not be kept level, and if lateral and vertical motions could not be prevented from being felt, or if there should be a slight falling-off in speed—none of which are events likely to happen—still the greatly-increased accommodation provided, the diminished effect the waves will have upon these ships to produce the motions complained of, and the superior speed they will possess over the present ones, upon the worst supposition

that can be made, constitute, we think, claims that will obtain for them the approbation of all who have ever suffered the misery and degradation of rough passages across the Channel in the existing steamers.

GALVANIC BATTERIES.

By the Rev. H. HIGHTON, M.A.

From the "Journal of the Society of Arts."

I shall not attempt to give any ultimate explanation of the phenomena of galvanism. It appears to me that it is true wisdom in science not to attempt to do more than to give an intelligent and comprehensive classification of the phenomena themselves. Deeper theories may sometimes be useful in suggesting experiments, if it be borne in mind that those theories must always be doubtful, and mere matters of guess, and, at best, simply provisionary. Thus Maxwell has shown that the laws of hydraulics may be applied to electrical currents, though he cautiously and wisely guards us against supposing that it follows from this that there is any real electric fluid similar to ordinary fluids. It would have been well if other well-known scientific men had been content to follow his example. In the same way I should object to the assumption of any ultimate theory of galvanism, beyond the mere intelligent and classified expression of the laws of the phenomena.

In the kindred subject of heat, I think great injury has been done by asserting that it is "a mode of motion," which has introduced many wild and visionary ideas. If the word "motion" be meant simply as a translation of the Greek word *κίνησις*, which includes nearly all kinds of change, and it also be meant that a change of temperature is a mode of motion in the ordinary English sense of the word, the assertion is, in a certain sense, true, but deceptive; if it be meant that simple heat, without change of temperature, is motion of any kind, this is not only extremely doubtful, but, I believe, absolutely untrue.* With regard to galvanism, then, I would merely say that it would appear that wherever there is a chemical there is also a galvanic action, which only requires proper arrangements to be made for exhibiting it.

Perhaps the simplest method of producing a galvanic current is by the formation or decomposition of water. Thus, if we have two plates of platinum, the surface of one of which is covered with a film of hydrogen, and the other with oxygen, on making a metallic connection between the two, a galvanic current passes, and the hydrogen and oxygen unite and form water. Conversely, if we take two metals, one of which has a greater affinity for oxygen than the other, and place them in water, then, on metallically connecting them, the water is separated into oxygen and hydrogen, the oxygen uniting with the more oxidizable metal, and the hydrogen being evolved on the surface of the other metal, and a galvanic current flows. I will show you both these actions by actual experiment. In both cases one pole of the battery is said to become positive and the other negative, and the action passing between the two is commonly called a galvanic current.

Take, again, the simplest of all forms of a galvanic battery—zinc and carbon, with a dialyte as it is called, of dilute sulphuric acid between them; the oxygen of the water unites with the zinc, and forms oxide of zinc; the sulphuric acid unites with the oxide, and forms a sulphate of zinc, and the hydrogen is evolved on the surface of the carbon. This double chemical action gives rather more electricity than the single action, as you see.

Now it is a well-known fact that chemical combinations frequently produce heat, and it is also a well-known fact that an electrical current in passing through a homogeneous conductor also produces heat; and it is an exceedingly interesting problem to ascertain what relation the heat of the chemical combination bears to the heat produced in the conductor of the current. An

* Aristotle, in his "Physics," suggests an important principle which might with advantage be studied by our modern theorists on the subject of heat. He says ("Physics" V., 1. 5.) Ἀλλ' ἴσως οὐχ ἡ λευκότης κίνησις ἀλλὰ ἡ λεύκανσις. That is, "But perhaps whiteness is not a mode of motion, but whitening is;" so by analogy heat and cold are not modes of motion, but heating and cooling are so—that is, in the Aristotelian sense of the word.

investigation of this kind requires the most delicate and expensive apparatus, much more delicate and expensive than I possess; but in searching into the records of the most trustworthy experimenters on this point, and comparing the results obtained by them, I have arrived at the following conclusions:—

1. That in all cases of galvanic action, the heat evolved in the battery, plus that in the exterior circuit, is exactly equal to the heat produced by the chemical action.

2. That, in most cases, a certain portion of that heat is retained exclusively in the battery, besides what is due to the internal resistance of the battery, and is not transmitted through the circuit.

3. That the potential of the battery varies, not only with the total chemical heat produced, but also with the proportion which that part of the heat which is transmitted through the circuit bears to the total chemical heat produced by the action of the elements of the battery. Indeed, the potential of a battery is exactly proportional to the amount of heat transmitted through the circuit by each unit of the atomic weight of the metal or other substance consumed or chemically changed. Thus, if we take two batteries, one of zinc, sulphuric acid and carbon, and another of zinc, sulphuric acid and copper, the heat evolved by the sulph-oxidation of the zinc is the same in both cases; but the potential of the former, and consequently the heat evolved in the circuit, is greater;—what becomes of the difference? Is the heat in some mysterious way lost? No; the surplus heat is not evolved in the circuit at all, but remains in the liquid of the battery, useless for the production of electricity. Now, it is an exceedingly remarkable circumstance that the only battery yet examined in which the whole of the heat produced is transmitted through the circuit, is that form of the Daniell's battery in which zinc, in a solution of sulphate of zinc, is used for the positive, and copper, in a solution of sulphate of copper, for the negative, and in which the sulphuric acid and oxygen are transferred from the copper to the zinc.

With zinc, strong sulphuric acid and platinum, about five-sixths of the heat produced is transmitted through the circuit, but this varies somewhat with the strength of the acid; with iron in sulphate of iron, and copper in sulphate of copper, only about two-thirds are transmitted; with copper in nitrate of copper, and silver in nitrate of silver, about $\frac{3}{5}\frac{3}{5}$. In this way we account for the circumstance that, with the same positive metal, the potential varies with the character of the negative metal, less of the heat of the oxidation of the positive metal being transmitted through the circuit, and more retained in the battery itself. I may as well say that I obtained these results by comparing some well-known experiments of M. A. Favre with some very important ones of M. Soret, which are scarcely known at all. I will illustrate this by showing you the amount of current derived from the oxidation of iron in conjunction with carbon, silver, and copper respectively.

But the whole subject of the relations between heat and electricity is one which requires deep and accurate investigation. M. Favre, in France, and Dr. Joule, in England, are the principal experimenters on this subject, and having spent very much time in carefully examining the published records of their experiments, I have no hesitation in saying that the conclusions they deduce cannot be accepted till they are repeated and varied with the most careful precautions, either by themselves or by others. It is much to be regretted that the committee of the British Association appointed three years since to investigate and report on the question in which these points are involved, and since reappointed from year to year, have not yet made public a single syllable by way of report as to their proceedings or conclusions.

I will only make one observation more before I leave this part of my subject, and that is that chemical actions which produce cold create a galvanic current, and therefore produce heat, as much as those actions which primarily produce heat. Thus, copper and carbon, acting on water, produce a current exactly the same in kind as zinc and carbon, although the heat produced by the oxidation of copper is less than the cold produced by the separation of the hydrogen and oxygen of the water. Again, you will see that while the combination of sulphuric acid with water, which produces heat, produces a galvanic current, the combination of acetic acid and water, which produces cold instead of heat, produces also a galvanic current of exactly the same kind as the combination of the sulphuric acid and water. Let me, then, show you these facts by actual experiment. And I may note, by the way, that it is a curious

circumstance that the combination of many acids and other substances with water, while they produce a contraction of volume, at the same time produce cold, not heat. In the combination of an alkali with an acid, which also produces much heat, you will see that a strong galvanic current is produced, and in this case the alkali, like the water in the former case, acts as the positive, and the acid as the negative. These circumstances, with many others, illustrate the fact that the view of heat, as given in Tait's "Thermodynamics" and other better-known treatises, namely that there is a certain absolute zero of temperature, fixed at—272 *C.*, where heat finally ceases to exist (just as there is a certain absence of motion when a body is at rest), and that all heat above this point is equivalent to a certain amount of mechanical force, is a view utterly erroneous; that, on the contrary, any variation of temperature, either upward or downward, involves mechanical force, and that the true zero of temperature is, when all contiguous bodies are of equal temperature, just as the true electrical zero is when all contiguous bodies are of an equal medium of electrical tension.

But I now turn to the more practical view of the subject. And here let me begin by saying that, in order to understand practically the action of a battery, the most essential thing of all is thoroughly to comprehend what is called Ohm's law. I have no hesitation in saying that the discovery of Ohm's law was to electricity not a whit less important, indeed I should say more important, than Newton's law of gravitation in astronomy and general physics; in fact it has been like the rising of the sun to travellers groping their way in darkness. It is now, of course, universally acknowledged as the great law of electrical action, though I need hardly say that, when first enounced, it was received by the scientific men of the day with the utmost scorn, and actually denounced as the wild ravings of a madman. But Ohm was then an unknown man—now his name is a household word with all electricians. This great law, then, is, that the quantity of electricity passing through each part of a circuit in a given time is proportional directly to what is called the potential or electro-motive power of the elements, and inversely to the total resistance of the circuit. Thus, to express it algebraically,

$$Q = \frac{E}{R}.$$

Again, the resistance of the circuit consists of two parts—the internal resistance of the battery, and the resistance of the rest of the circuit. Calling these R′ and R″, we have the equation,

$$Q = \frac{E}{R' + R''}$$

and in the practical comprehension of this equation under the different circumstances to which it is applicable consists the whole difference between a good and a bad electrician; everything as regards the relation between batteries, the work they have to do, and the cost of doing it, depends upon this equation. If we have many similar cells in a battery, say n cells, then the equation becomes

$$Q = \frac{n\,E}{n\,R' + R''}$$

Q represents the amount of chemical action going on in a given time in each cell, and if R″ be small, it is plain that, though with many cells we get many times the waste of zinc and other elements of the battery, we get no addition to the current; on the other hand, if R″ be large, we want a good many cells to produce the same current, and, in fact, as I said before, in the practical application of this equation to every varying case lies the whole art of the proper or improper use of a battery, and the art of using such batteries as are properly suited to the object desired to be attained. It will be obvious, from what I have said, that the main points of merit in a battery are:

1st. A large potential, or electro-motive force.

2d. A small internal resistance, for where there is much internal resistance a large part of the power of the battery is wasted in itself, in overcoming—if I may so speak—its own friction. To these two points I may add two more, viz.:—

3d. Constancy, or a power of keeping up an action nearly uniform.

4th. Permanency, or the power of working for a long time without attention or fresh making up of the battery.

When I say that the heat produced in a given time—and in some cases the magnetic power—is as the square of the quantity, and not simply as the quantity, you will see at once the great importance of having a large potential.

The two instruments I have here will

serve to show the first three points in different batteries, namely, the potential, the internal resistance, and the constancy for at least a short time. The permanency must, of course, be a matter of time to ascertain. The first instrument, a galvanometer with a large resistance, will, I think, show practically better than any other the potential of a battery. By either observing the degree of deflection with the same resistance, or the resistance through which the same degree of deflection is produced, we get a good practical idea of the potential of a battery. And this is really all we want; an exact theoretical determination is valueless, as it is always varying, more or less, from moment to moment.

I will now show you the practical potential of a large number of combinations. Let us take, as a convenient standard, zinc in sulphate of zinc, copper in sulphate of copper.

It is more convenient in practice, though a little larger than the British Association unit, which they call a "Volt," in which the negative is copper in nitrate of copper.

You see the degree to which it attains; now, let us compare with this the following elments :—

Zinc, dilute sulphuric acid platinum.
" " carbon.
" " silver.
" " copper.
" dilute sulphuric (‖)* nitric acid, platinum (or Grove's form.)
" " (‖) nitric acid, carbon (or Bunsen's form.)
" a mixture of dilute sulphuric and chromic acids, and carbon, without a porous cell, as recommended by Roscoe and Bunsen.
" dilute sulphuric acid (‖) carbon and mixed sulphuric and chromic acids.

I add a little permanganate of potash to the negative, and you see the potential raised a little. Now I will show you some forms of my own.

Zinc, solution of potash (‖) carbon packed in a mixture of carbon, precipitated sulphur, and peroxide of manganese with dilute sulphuric acid.
Zinc, common salt (‖) " "

Next what is in most respects, I think, the most convenient, and best, and cheapest in action (for the power produced) of all batteries :—

Zinc, common salt (‖) carbon packed in granulated carbon peroxide of manganese, with a mixture of sulphuric, nitric, and chromic acids.

* The mark (‖) is intended to denote a porous diaphragm.

The potential of the first of these then is, as you see, very high, much higher than a Grove or a Bunsen, indeed nearly fifty per cent. higher; the second and third also considerably higher; the third is very constant, very enduring, and, from the peculiar chemical action of the materials, emits none of those poisonous nitrous fumes which have so seriously and permanently injured the health of many who have used the Grove or Bunsen batteries. Now we will try the potential of iron instead of zinc; this, you will see, is about three-fourths that of zinc, so that four cells of iron will be about equivalent to three of zinc. But as iron is about one-third the price of zinc, and is much less liable to be affected by local action, it would seem as if there was great advantage in using iron. But as every pound of iron consumed will take a little more acid and manganese than the zinc (that is, in the proportions of eight and seven), and the internal resistance of four cells will be more than that of three, there is, on the whole, probably not much economy in using iron. Here is another battery in which no acid is used, and in which the potential is as high, or nearly as high, as a Grove, and very constant in its action. It is zinc, solution of salt, (‖) carbon, and the peroxide of manganese, with a mixed salt of sodium, tin, and mercury. For telegraphic purposes, where the use of acid is thought objectionable, I know no better form.

But instead of zinc or iron, or indeed any metal, we may use any oxidizable liquid, and collect the electricity derived from its oxidization by means of a carbon plate. The cheapest, probably, of all is common salt; you see this gives a very fair potential, in fact not very short of a Daniell. Again take sulphate of protoxide of iron, a very cheap material, which may be kept in a state of protoxide by placing in it pyrites or other sulphide of iron, which is a material almost valueless. Cyanide of potassium, you will see, gives a good potential; also hyposulphide of soda, and sulphide of soda or potash. You will observe that the potential of this last is very much greater than a Daniell, and approaches that of a Grove. Sulphide of calcium—a waste material in many places—gives a very good potential. Again, brandy and water, sugar and water, milk, flour and water, all of which, being oxidized by the oxidizing materials of the negative side of the battery, produce a considerable galvanic current.

Indeed, with these kinds of materials the battery plays the same part as the stomach and lungs of the animal body, the negative part of the battery supplying oxygen to oxidize the food materials of the positive part, just as the lungs furnish oxygen for oxidizing the food supplied to the stomach and brought into circulation in the blood. You will observe that milk and tea are more easily acted on, and give a larger potential than brandy and water or flour and water. But before I conclude this part of my subject, I ought to show you the potential of some other of the common forms of battery, namely, the Wollaston, the Smee, and the Le Clanché. You will see they are much inferior to some of the forms I have shown you, besides having other disadvantages which I shall show you in due time.

Well, let me next show you the internal resistance and constancy of some of the common forms of battery. In order to show this properly, we must, of course, take elements of an equal size. This instrument is a galvanometer of very small internal resistance, so that, practically, it shows you what is the internal resistance of the battery, as that is the main element of resistance. Of course the potential also affects the result, so that the degrees in this instrument will practically show you the combined result of potential and small resistance, where a large amount of current, with a small resistance, is required; and the loss of power in a minute (I cannot afford time to show you the effect of a longer duration) will give you some idea of their constancy.

Let us just take that modification of the Daniell now used in the post-office and generally for telegraphic use. You have seen that it stands low in the scale for potential; and you will now see that for small internal resistance it stands very low indeed, but that its constancy for one minute at least is perfect. But still the amount of electricity produced in a minute is so very small that it ought to remain constant, there being so little expenditure of force in the time. Now, compare with this, two forms of battery introduced by myself for telegraphic purposes—zinc in salt or dilute acid for positive, and carbon placed in granulated carbon and peroxide of manganese with dilute acid for negative. You will see the comparatively enormously large quantity of electricity which this produces; though in the course of a minute, where there is no resistance, it, of course, partially exhausts itself, the peroxide not being able to furnish oxygen rapidly enough for the supply; but, after a short interval of rest, it recovers its full potential. On the London and North-Western Railway ten of these cells were found to work to Manchester equally well with 60 of the ordinary sulphate of copper batteries; not, of course, that the potential is six times as large—indeed, it is not more than double; but in damp and wet weather, where there is much leakage from the wires, the small internal resistance of these batteries enables them to supply enough electricity to make up for the leakage, whereas the larger internal resistance of the Daniell batteries prevents them from supplying in a given time more than a comparatively small given quantity, which will not bear much loss from leakage. I am glad to say that this form of battery is being fast adopted for railway use. Then we try the Wollaston—a small potential, a small resistance, and a very rapid fall of power; then the Smee—a small resistance, fair potential, and in consequence of the rapid escape of hydrogen, considerable constancy. To this battery the hydrogen fumes are a great objection. Next, try the Le Clanché, a fair original potential, moderate resistance, and rapid fall of potential. Next, the form I mentioned before as introduced by myself, with a higher potential than the Le Clanché, and much more constant, though, like the Le Clanché, used without an acid, and therefore quite as permanent. It is simply a solution of common salt with a combined salt of sodium, tin, and mercury in the negative. This combination has the peculiar property of being able to extract rapidly the oxygen from the peroxide of manganese. The tin causes in time a little local action, but if it be left out, the mercury by itself cannot so rapidly extract the oxygen, and the local action caused by the tin is very small indeed. Next the "Grove," a high potential, very little resistance, even an increase of potential as the liquid gets warm; Bunsen the same; but both, after a short time, producing intolerable poisonous fumes, which produce dangerous inflammation of the lungs, take away the voice, and when a man's system has once been injured by them, act upon the lungs on subsequent occasions with the utmost rapidity. For myself, I am now so sensitive to them, that I cannot expose my-

self to them for even a few minutes without losing my voice and my chest getting seriously affected; besides, they are far from permanent, as a few hours exhaust their power. Next, I try the bichromate battery, without porous cells; small resistance, high potential, but soon losing its power, and very expensive and wasteful in use, destroying itself by a single night's action. Next, the bichromate, with a porous cell, high potential, moderate resistance, moderate constancy, but very expensive in use. Next, let me take my own form, which for general practical use—as for induction coils, for keeping up a powerful magnetic action when required, and other such purposes—I think is far superior to all others. Zinc in salt, carbon packed in granulated carbon and peroxide of manganese, filled in with dilute sulphuric acid, mixed with a little nitric and chromic acids. Here is very high potential, as I showed you before, moderate resistance and great constancy. I have had them standing for months, used occasionally, and losing but little of their original potential.

For electro-plating, in power, convenience and long endurance, they exceed all others. Some electro-platers prefer iron as the positive, some zinc; for each has his own peculiar preferences and modes of working; but they are now becoming largely adopted, having more than the power of the Bunsen, without the inconveniences, and lasting, I may say, 30 times the length of time. Some electro-platers have had them in daily use for two months at a time. The chromic acid has the especially valuable property of absorbing all nitrous fumes.

To show you the power of the battery, here is an electro-magnet magnetized by a single cell. I will defy the strongest man in this room to separate the soft iron keeper from the magnet.

Where very great constancy and a very large current of electricy is not required, the nitric and chromic acids may be omitted, and then the local action becomes next to nothing; but with the latter a moderate-sized battery of a single cell has been used for plating six dozen forks at once.

I am afraid that I have occupied you too long, but as it is, I have been obliged to compress my matter unduly, and to omit many points on which I should have wished to dilate.

RAILWAY SPEED.

From "The Engineer."

The advantages which the public now enjoy in having the time occupied on long journeys by railway reduced to a minimum appear to be insufficiently known to be fully appreciated. The efforts which the companies have been making in order to obtain the maximum of speed combined with an immunity from accident, in so far as human agency and the most perfect mechanical appliances will avail, have been unremitting; and on many of the lines the result has been that a service of well equipped and rapid trains has been established that will probably, so long as the present construction of road and vehicle exists, never be surpassed for speed and comfort. Doubtless the improvement is not wholly traceable to a desire on the part of the companies to let the public reap the whole of the benefits, but may in many cases be attributed to a spirit of emulation which has followed on the healthy competition engendered among the rival companies themselves. It is evident, however, that so long as the arrangement which exists among rival companies of charging the same fares between all competitive points continues in force, the public cannot fail to reap the full advantage to be gained from the high speed and superior accommodation. It matters not to them by what route they may travel, seeing the charges are the same, and every endeavor is used to make the time occupied on the journey by each of the competing lines uniform. It is pretty generally understood now among the companies themselves that high speed means a high ratio of working expenses, and the wonder is that, when rates are made a matter of mutual arrangement, the time to be occupied should not also be agreed upon, as by that means there would be secured equal advantage in reduced working cost, and neither would secure an undue advantage over the other if each company modified the present speed.

There are very few of the companies who now seek to compensate themselves, for the

extra wear and tear produced by fast trains by charging an augmented fare, "express" fares being almost wholly discontinued. Doubtless, from the long experience they have had, especially on the northern lines, they have found the practice did not answer. It is possible, too, that where so much complication exists as in some of the parts reached by the northern companies it is impracticable to arrange the trains at certain points in such a way as to be able to distinguish between express and ordinary. These companies now charge, with very few exceptions, one uniform scale by all trains; and also, as only recently introduced, afford the public at the same time the opportunity of travelling at express speed for a third-class fare.

Where no competition exists it will generally be found there is little speed, and we fear too less comfort and accommodation, than where two or more companies are striving to secure the traffic to and from the same points. The greatest speed is generally found where one company has a circuitous route to traverse in reaching a point also in the possession of a rival company. It must be a matter of the greatest satisfaction to the travelling public to know that in such cases, where even an unusual rate of travelling has to be kept up by the trains of a company so situated, there is nothing more inconsistent with absolute safety, thanks to improved road-beds, block telegraphs, and other appliances, than is to be found on the line possessing the shorter and more direct route. The companies, no less than the travellers themselves, are to be protected from the result of accident, and in consequence vast sums have been expended by the companies in fitting their lines with the most perfect means attainable for averting anything of the kind. By means of carriages connected at the rear of the trains by slip couplings, which enable them to be detached while the trains are running at full speed, it is possible also to convey passengers to the more important points of the journey without stopping the train; although, necessarily, it is impracticable to take up passengers at such places. By means of water troughs, too, from which the tender may be refilled while travelling, as on the London and North-Western, the engines are able to travel longer distances without stopping for a fresh supply of water, thus shortening the delay which is otherwise unavoidable.

In order to show the extent of the improvement that has been effected in the rate of travelling, as also what the actual speed now attained by the principal express trains is, we have selected a few of the fastest from the time-table books of nine of the larger companies having termini in the metropolis. No doubt it would be possible to show that other companies—the North-Eastern and Caledonia for examples—run trains as fast or faster than some of those selected; but it will suit our purpose to confine ourselves to the companies stated. It is only where a run of twenty miles or upwards is made, and, where practicable, the speed on different portions of each system that we have selected as the basis of the calculations; but the highest speeds, as far as possible, are always taken. The following will, therefore, be found to record a few of the fastest on each line, the length of the run, and the speeds they travel at.

The mean averages of the table, column 3, are of course, arrived at by taking the total time occupied in running the total of the distances shown; and, placed in the order of priority, they are as follows:—

	Mean average on each line.
Great Western	51
London, Brighton and South Coast	45¾
Great Northern	45½
London, Chatham and Dover	44¼
South-Eastern	43¼
North-Western	42¾
Midland	41¼
South-Western	40¼
Great Eastern	37¾
General average	43¼

It will thus be seen that the average speed of the express trains over the Great Western line is highest, being no less than 5¼ miles per hour greater than that of any other company, and 7¾ miles more than the general average recorded. These averages, it must be remembered, are arrived at by taking the speed on different parts of each company's line, and will not, therefore, be applicable to certain portions of the lines where express trains are numerous and usually run faster. For example, on the Great Northern line between London and Peterboro' nearly all the express trains run at a speed of over 50 miles an hour, and an average struck for that part of the line would therefore yield a much higher figure than 45½ miles, which is the company's general average over all the lines. It is probable that, in the great number of express trains run over their system, the Great

Northern Company may be considered the leading company in point of speed. On the other hand the Great Eastern show an average of 37¼ miles per hour only, or about 14 miles less than the Great Western; this company having only two trains running out of London which can be said to be "express," and as these are what the present calculation has been based upon, the line may be classed as generally slowest. Doubtless the cause of its exceptional position in this respect is to be traced to the almost entire absence of any opposition at the important points served by the company.

Selecting the cases in which the highest speeds are attained on any part of each of the different lines, some very remarkable examples of quick travelling are obtained. We prefer giving the trains, and other particulars, as we have been able to arrive at them from the means in our possession, and in the order of priority. They are as follows:—

Company.	Stations.	Train.	Miles.	Time.	Speed per hour.
				h. m.	
Great Western	Paddington to Swindon.....	11.45	77¼	1.27	53¼
South-Eastern	Tunbridge to Ashford	4.55	26½	0.31	51¾
Great Northern.....	London to Peterboro'	10 0	76¼	1.30	51
Chatham	Chatham to Dover.....	7.40	43¼	0 55	47½
Brighton	East Croydon to Brighton	5.0	40¼	0 51	47¼
North-Western.	Rugby to Crewe.....	10.0	75½	1.40	45¼
Midland	Leicester to Trent.....	10.0	20¾	0 28	44½
South-Western	Salisbury to Yeovil.....	2.10	40¼	0 56	43¼
Great-Eastern	B. Stortford to Cambridge.....	5.0	25¾	0.37	41
Average fastest speed.	.....	....	425½	8 55	47¾

Here again we find the Great Western Company at the top of the list, with a run of 77¼ miles at an average of 53¼ miles per hour. This is no doubt the fastest running to be found anywhere even for the shortest distances. Such a speed, barring stoppages, would bring Edinburgh within 7½ hours of London, instead of the present 9½, which, when first introduced, was looked upon as marvellous travelling. The Great Western is a circuitous route to the district chiefly served by this particular train, and the exceptionally high speed at which it is worked is to enable the company to hold its own against the London and South-Western, who have a shorter and more direct access to Exeter by about 23 miles. The South-Eastern Company make a short run of 26½ miles, at the rate of 51¼ miles per hour, but it is on a part of the line well adapted for such sharp practice, and the journey occupying only 31 minutes, the case is not to be classed before the example of the Great Northern. This Company, as already stated, run all their through express trains at a very high speed; and the fastest is that stated, running too, as it does, over a very crowded line between London and Peterboro', a distance of 76¼ miles, in just an hour and a-half—an average speed of 51 miles an hour. The Brighton and the London, Chatham and Dover examples, too, must be regarded as highly superior. It is more than probable that in the average of 47¾ miles which the above figures yield as the mean of the highest speeds recorded on each of the lines, the English companies will be able to concede at least 10 miles per hour to the highest averages shown on the lines of any other country of the world, the "lightning expresses" of America included.

The examples of fast travelling are not confined to the several trains while running on the parent line only, but are continued, in the case of through trains, over the lines of the connecting companies. As instances of the kind may be mentioned the Exeter and West of England express of the Great Western Company, which runs the entire distance between London and Exeter, 194 miles, in 4¼ hours, including three stoppages, or about 46 miles an hour. The Scotch express of the Great Northern Company, which performs the journey between London and Edinburgh, a distance of 400 miles, in 9½ hours, including six stoppages of some duration, also gives an average on the whole

Company.	From	To	Train.	Time taken.	Miles.	Speed per hour (miles).
				h. m.		
Great Northern	London	Peterboro'	10 0	1 30	76¼	51
	Grantham	York	10.0	1.54	84¾	44⅛
	Peterboro'	Grantham	10.10	0.40	29	43½
	Grantham	Retford	8 30	0 42	33¼	47½
	Retford	York	8.30	1.16	51½	40¾
				6.2	274¾	45½
Great Western	Paddington	Reading	9.15	0.43	36	50¼
	Do.	Swindon	11.45	1 27	77¼	53¼
	Swindon	Bath	11.45	0.34	29½	52
	Reading	Swindon	5.10	0 53	41¼	46¾
				3.37	184	51
London and Brighton.	East Croydon	Brighton	4.0	0.54	40¼	44¾
	London Bridge	Do.	5 0	1.5	50½	46¼
	Horsham	Chichester	5.0	0.43	31¾	44¼
	East Croydon	Brighton	5 0	0.51	40¼	47¼
				3.33	162¾	45¾
London and Chatham.	Herne Hill	Dover	7 40	1.40	71	44⅛
	Chatham	Do	7.40	0.55	43½	47½
	Herne Hill	Chatham	8.35	0 44	30½	41¼
	Chatham	Canterbury	8.35	0.38	27¼	43
				3.57	175¼	44¼
Great Eastern.	Bishopsgate	B. Stortford	11.45	0.58	32¼	33½
	B. Stortford	Cambridge	11.45	0.37	25½	41
	Bishopsgate	B. Stortford	5.0	0.53	32¾	36½
	B. Stortford	Cambridge	5.0	0 37	25¼	41
				3.5	115	37¼
London and North-Western.	Euston	Rugby	7.15	1.55	82½	43
	Crewe	Chester	7.15	0 30	21¼	42½
	Chester	Holyhead	7.15	2 7	85¼	40¼
	Rugby	Crewe	10.0	1.40	75½	45¼
	Crewe	Preston	10.0	1 13	51¾	42
	Preston	Carlisle	10 0	2.19	90	39
	Rugby	Stafford	8.0	1.7	51	45½
	Stafford	Crewe	8.0	0 36	24½	40¾
				11 27	481¼	42¼
London and South-Western.	Waterloo	Basingstoke	10 50	1 15	47¼	38¼
	Do.	Do.	2.10	1.7	47½	42¾
	Basingstoke	Salisbury	2.10	0.50	35½	43
	Salisbury	Yeovil	2 10	0.56	40¼	43¼
	Yeovil	Exeter	2.10	1.9	47¼	41¼
	Waterloo	Basingstoke	3 15	1.16	47¼	37¼
	Do.	Guildford	4.0	0 50	30¼	36¼
				7.23	297¼	40¾
Midland.	St. Pancras	Bedford	10.0	1.8	49¾	43¾
	Bedford	Leicester	10.0	1.7	49¼	44
	Leicester	Trent	10.0	0.28	20¾	44½
	Trent	Chesterfield	10 0	0.37	26¼	42½
	Derby	Manchester	5.0	1.40	60	36
				5.0	206	41¼
South-Eastern.	Cannon street	Tunbridge	4.55	0.43	28¼	39½
	Do.	Dover	7.45	1.11	75½	44¾
	Tunbridge	Ashford	4.55	0.31	26½	51¼
	New Cross	Canterbury	3.50	1.37	65¼	40½
				4.32	195¼	43¼

time occupied of 42 miles an hour. The London and North-Western Company's "limited mail" also travels from London to Glasgow, a distance of 404 miles, in 10 hours and 22 minutes, and therefore averages 39 miles an hour.

The examples of runs of 50 miles and upwards without stopping are numerous. The continental trains of the London, Chatham and Dover run from Herne Hill to Dover, a distance of 74 miles, without stopping; and the South-Eastern between Cannon street and Dover, 75¼ miles. The Great Western run from Paddington to Swindon, 77¼ miles, without stoppage; the Great Northern from London to Peterboro,' and from Grantham to York, 76¼ and 84¾ miles respectively, while the London and North-Western Company's Irish mails run from Chester to Holyhead, a distance of 85¼ miles, occupying 2 hours and 7 minutes on the journey, without stopping, being the longest run recorded.

From the various examples we have quoted it will be perceived that the oft-mentioned "mile a minute" speed is, to say the least, somewhat apocryphal. A few of the above-mentioned trains may at times attain such an extreme velocity, but it can only be on some unusually favorable bit of road, and maintained at the most for a few minutes only. There is the best of evidence for stating that such a speed is scarcely ever exceeded, and that sufficient time is always allowed for even the fastest trains to perform their journey to time, without approaching nearer than by several miles an hour to such a fancy velocity.

In a subsequent article we will endeavor to give some particulars as to how these great speeds are accomplished, the class of rolling stock used in the trains, and a few practical details as to the consumption of fuel, and as to the bearing of express speed in relation to the question of working expenses and the general economy of the railways.

SCREW SHAFTS.

From "The Engineer."

In another page will be found a letter which calls attention to an unusual number of "break downs" in the machinery of steamers. To the list given by our correspondent we may add the Atrato, which broke her crank shaft several weeks ago, and the Chimborazo, Pacific Mail steamer, which had her machinery disabled on the 26th of November. By far the greater proportion of these casualties consist in the breakage of screw shafts, as pointed out by our correspondent. We do not endorse all that he says, and we may digress here for a moment, to explain that we are never responsible for the opinions of our correspondent—a statement which we find it necessary to make because some misconception appears to exist on this point among certain of our readers. As he has put the matter, we fail to understand precisely what Mr. Haworth means by centrifugal force and a limit beyond which it is unsafe to drive machinery. The "thumping" to which he refers is obviously the result of the thrashing action of the screw familiar to every engineer who has been at sea in a gale of wind. On the other hand, however, it is well known that there is a velocity of revolution beyond which it is unsafe to drive any engine. Screw shafts are broken principally by the racing of the engines in a gale, when the screw is alternately buried deeply and lifted almost out of the water. This is a very general statement of a well-known truth, but it conveys little or no definite information. The resistance offered to the screw is apparently no greater when the screw is suddenly immersed than it is when the screw is steadily working at its proper depth. It remains to be explained why, under such circumstances, a shaft should give way. The explanation appears to be this: The reciprocating parts in a large screw engine represent considerable masses; and the extra strain put on the screw shaft when a racing propeller sinks in the sea to its proper level, consists of the stored up energy in those masses of metal the velocity of which is suddenly arrested. Let us suppose, for example, that the piston, cross-head, connecting rod, and crank weigh three tons, or 6,720 lbs. When the screw races we may assume that the velocity of these amounts to 12 ft. per second, while the normal velocity is 6 ft. per second, this piston being at mid-stroke. The stored-up work in the moving mass, under the first condition, will be 15,025 foot-pounds,

while in the latter case it will be 3,763 foot-pounds. When the propeller is pulled up suddenly by being immersed, the engine is brought back to its normal speed in a very small fraction of a revolution, and the difference between 15,025 lbs. and 3,763 lbs.=11,262 foot-pounds, must be expended upon something. Obviously that something is the water; but the water is practically very much the same as a solid body, and the whole surplus momentum of the engines may be absorbed while the piston is moving over little more than 1 in. During this minute fraction of time the strain, referred to the crank pin, and due to the arrested momentum, will amount to not less than 112,620 lbs., or about 50 tons. The momentum of the propeller itself tends materially to reduce the strain on the screw shaft; and it is indisputable that the use of a heavy propeller is a direct means of protection for a screw shaft in a gale, by reducing the tendency to race in the first place, and by aiding to overcome the resistance of the water when re-immersion occurs in the second place. There are, of course, limits beyond which it would be injudicious to increase the weight of a propeller; but a very instructive lesson could be gathered from a statement of the weights of the propellers and those of the reciprocating parts of a large number of screw steamers. It would then be found, we think, that, *cæteris paribus*, as the weight of the propeller increased, so did the longevity of the screw shaft.

All the evils of racing can, however, be almost, though not entirely, counteracted by the aid of good marine governors, of which there are a number in the market from which the steamship owner can pick and choose; but no governor can prevent the ultimate destruction of a screw shaft worked pretty hard. The larger the factor of safety—in other words, the smaller the strain per square inch of section brought upon the metal of the shaft—the longer it will last; and it is quite possible to load a screw shaft so lightly that it will wear out the ship. In practice, however, screw shafts have a factor of safety varying nominally between ten and six; but in gales the limit of strength is often very nearly approached, the factor of safety no doubt coming down now and then, to two or three. Under such circumstances, the failure of a shaft is simply a question of time; and it would not be altogether impossible for careful shipowners to determine when it was proper to take a shaft out and anneal it, or to put in a new one. The duration of locomotive crank axles is tolerably well known. Under ordinary circumstances it may be taken at about 40,000 miles, but it is an instructive fact, that crank axles with inside bearings only, will run twice the mileage of those with outside bearings. Something might, we think, be done by marine engineers to reduce the chance of breakage by paying attention to the way in which a shaft is put to work and to the proportioning of its parts. Any one who will compare drawings of a locomotive crank shaft with those of the crank shaft of a screw engine, cannot fail to see that there is a wide difference. The crank pins of the former are carefully rounded out to a large radius, while those of a screw shaft are almost always straight, with very small sweeps at the crank arms. A locomotive crank shaft, 7 in. in diameter, would not stand for a month if made like a screw engine crank shaft of the same diameter. The marine engineer might, with advantage, take a lesson from his brother of the railway.

Two other matters not sufficiently considered are, the counterbalancing of the engines and the position of the screw with regard to the cranks. As regards the first, we shall only say that bad balancing is almost worse than no balancing at all; and in cheap screw engines the balancing is usually of the most inefficient character, the weights being placed in the turning disc or coupling, instead of being hooped on to the cranks. As regards the second, we are not aware that any engineer has hitherto given the subject a thought. The screw shaft is coupled up to the engine shaft without any regard being paid to the relative position of the crank and the propeller blades. With three and four-bladed fans this is of little or no moment, but with two-bladed fans it is obvious that the position of the blades should be such relatively to that of the cranks, that when the driving moment is greatest the screw resistance ought also to be greatest. Most of our readers are, no doubt, familiar with diagrams of crank shaft moments for screw engines of various types, but we venture to think none of them can find a diagram of screw resistances calculated for one revolution. As far as can be learned, the resistance offered to a rotatory impulse is at a maximum when a fully immersed two-bladed screw is straight up and

down, because of the great immersion of the lower blade, and is at a minimum when the fan is horizontal, or nearly so. With engines working very expansively this point is worth a consideration which it has not yet received. Any competent engineer with two diagrams of moments of impulse and resistance before him will soon see that there is one position of the propeller with regard to the crank better than any other for every case, and the adoption of this position would tend to make the engines run more evenly and so eliminate in some measure the chances of a breakdown.

It is not a little remarkable that, notwithstanding all the ingenuity expended on the marine engine, no one has thought of devising some method of patching up a broken screw shaft at sea. Our American exchanges contain an account of the successful repair of a broken-down marine engine in a large ocean steamer by the ship's carpenter. A cylinder lid was smashed. There was no spare lid on board. Baffling winds prevailed; the ship was driven far out of her course, and the crew and passengers were being put on short allowance, when it occurred to the carpenter that he could make a cylinder lid. This he did of three thicknessses of 3 in. teak planking, and, by working the engine at a pressure of a couple of pounds of steam per square inch only, and with a moderate vacuum, the lid was made to last until the ship was got into harbor, steaming easily at the rate of five or six knots per hour. There is nothing impossible about this story, and many a seagoing engineer could tell remarkable tales of wonderful expedients used to cobble up a broken-down engine. As regards the fracture of a shaft on board a screw steamer, it is obvious that if the smash is just at the after journal, nothing can be done; in some cases, however, the after engine remains available. But the breakage of screw shafts is nearly, if not quite, as common a catastrophe as the breakage of crank shafts.

It has been suggested to us that in such cases an easy remedy could be made available. We have the engine all right, and the screw shaft all right with the exception of the break; why not supply every screw ship with a coupling-box or disc which could be brought into requisition to unite the broken ends? The coupling might be ordinarily carried on the shaft, so as to be ready at a moment's notice, and when the breakdown occurred would only require to be moved up to the fracture. There is fair scope here for the exercise of ingenuity. It may be urged that such an expedient could not be used in one out of ten cases of broken shafts. Even if this were true—and it is not—the device would be worth having, and no one would appreciate its value so much as those who availed themselves of its benefits.

THE A B C PROCESS.

From "Engineering."

II.

In a previous article we directed attention to most of the schemes that have been proposed for the utilization of sewage, and to some special points which characterize the A B C process. It has been stated that the use of blood, as drawn fresh from the animal, is an essential feature of that process. But with it is included, according to the various patents taken out by the Native Guano Company, a large number of other substances considered as aiding that process in not only purifying sewage, so as to render the resulting effluent water fit to run into any stream, but also the production of a fertilizing manure, which, to copy the opinion (in part) of Liebig, would return to the soil that which the animal had, during its existence, extracted from it.

Pursuing the investigation of the A B C process, the following points of chief interest arise beyond those already stated.

A large proportion of clay, amounting in most cases to about half the weight of the resulting native guano, is employed. The office of the clay may be simply described by stating that aluminic silicate has the power of attracting to itself certain animal matters, as is well known in the ordinary commercial process of fulling work. This fact, however, does not seem to have suggested itself to the early patentees of the process, who employed clay of *any kind*, if some of them

deserved that title. For example, a quantity of common marl was selected as a clay, that contained about 20 per cent. of carbonate of lime. If, however, a suitable clay be employed in treating sewage, it has many excellent properties. It is a matter of common knowledge that clay containing a certain amount of alumina, soluble in any of the so-called mineral acids, has an effect on animal matter resembling that of the alkalies, although possessing no alkaline properties of its own. Independent of the power of such clay to precipitate animal matters, and even, as Professor Way has stated, to remove chlorides, its addition in the form of a resulting sewage manure would, without doubt, prove valuable to sandy soils. Such a silicate of alumina, or aluminic silicate, would thus aid in retaining moisture, and consequently carbonic acid and salts of ammonia, in both cases by mechanical fixation.

The employment of any sulphate or other salt or kaloid of aluminium is to be recommended in treating sewage. Hence the A B C, the PhosphateSewage, and Anderson's companies have been unanimous in using some form of aluminous combinations for that purpose. But all have blinked the fact, that salts of iron, which are isomorphous (in alums) with those of alumina, are really, in part, if not equally, efficacious as sewage purifiers. Had Mr. Dover, to whom we have already referred, possessed the knowledge of a matured chemist, we should scarcely have heard of some of the more modern schemes of chemically treating sewage.

The use of charcoal is another feature of the A B C system. The advantages of this material cannot be over-rated as a deodorizer. We could refer to, at least, a score of patents in which it has been selected for disinfecting purposes. In 1855-56, Dr. Stenhouse, of St. Bartholomew's Hospital, and Dr. Forbes Watson, fomerly of the Indian medical staff, took out a patent for its use for rendering the miasmatic air of Indian climates purer by filtration through that material, before the atmosphere reached the lungs of the patients. We believe that Mr. Wicksteed, in 1854, was one of the first to use a kind of charcoal (for purifying sewage) formed from the waste of the prussiate of potass (ferrocyanide of potassium) manufacture; yet this has since been re-patented. Similarly, in the case of purification of gas, the use of oxide of iron was patented years before the present patents were brought into actual use. The truth of the patent history of our country would show some singular revelations in regard to "original" inventions.

We have, then, disposed of the chief "elements" of the A B C process; we now proceed to state and discuss its use and results.

The blood, clay, charcoal, and sulphate of alumina, or alum, are mixed together, so as to make a kind of semi-liquid, afterwards diluted with water. The proportions employed are thus stated in the last patent (30th December, 1870, No. 3399.) "In practice we find the following proportions give good results with ordinary town sewage:

"Ingredients contained in 100,000 parts of the A B C mixture:

	Parts by weight.
Crude sulphate of alumina	3,000
Charcoal	4,000
Clay	10,000
Blood	6
Water	82,994"

The above formula gives that in which blood is employed. If, however, glue be substituted, then one part of that substance is used, the remaining difference of five parts being made up with water. "The quantity of mixture to be added to the sewage will be about one volume of the said mixture to 100 volumes of sewage, but, of course, the proportions and constituents will be subject to variation, according as the character of the sewage is found to change, the 'feed' being regulated as required, by any suitable mechanical means."

Such is the A B C mixture described in the words of the patentees. If about two drachms of it be added to about twelve ounces of ordinary sewage, contained in a hydrometer glass, some singular and sometimes beautiful results are obtained. After the sewage and mixture have been well stirred together, an immense number of flakes form. These gradually aggregate into larger masses which eventually settle to the bottom of the vessel. For some time fine particles remain suspended, but after a lapse of six to twelve hours the supernatant liquid becomes perfectly clear, tasteless, and inodorous, no matter how filthy or colored it had previously been. Leeds sewage, which is generally deeply colored with all kinds of dye-stuffs, may thus be rendered as clear as distilled water, and could not be distinguished in this condition, by drinking

it, from the ordinary water supply. Any person can easily verify the result by proceeding according to the instructions here given.

This fact establishes the claim of the Native Guano Company in regard to the power of the process of rendering sewage clear, inodorous, and tasteless, but not to an unlimited degree. The perusal of our observations given in some preceding articles, entitled "Notes on Sewage," will afford an explanation of the limits to the efficiency of the process. Take for example two extreme cases. If the same quantity of A B C be added respectively to the same quantities of the sewage of Leamington and of Leeds, the latter will readily afford a clear effluent, while the Leamington sewage will be very imperfectly acted on, because the latter is highly charged with animal matter, while the Leeds sewage is enormously diluted with water. At first sight it would appear that the addition of more A B C to the Leamington sewage in proportion would overcome the difficulty; this it does to a certain extent, but not with such satisfactury results as are obtained by the action of the A B C on a dilute sewage. This point, however, will be further dealt with when we consider the relative qualities of the manure produced from various kinds of sewage.

The important question arises here as to what extent the A B C process purifies sewage, so far as the quality of the effluent is concerned. Unfortunately a serious difficulty arises, as to the results of chemical analysis in determining the amount of "organic nitrogen," which is considered as indicative of sewage contamination. The following instances, which came, with scores of others of a like nature, under our personal observation, will show the little reliance that can be placed on chemical analysis for absolutely determining the fitness of water for drinking purposes, and consequently the character of an effluent produced by the treatment of sewage by irrigation, or any other process. In 1871 two leading members of a local board sent up samples of the well water they respectively employed for domestic purposes, to two of the most eminent chemists in London. The reports returned were diametrically opposed to each other. According to one, the water was replete with sewage contamination, and utterly unfit to drink; while the other chemist reported the water as quite free from sewage contamination and excellent for drinking purposes!! But to still further show the difficulty that exists in this respect, we quote the views of Professor Frankland, as stated in a letter contained in a Report on the Water Supply (Metropolis*). He remarks:

"It cannot be too widely known that chemical analysis is utterly powerless to detect any matter positively injurious to health in any of the forms of animal refuse which go to contaminate water." At a lower part of the page referred to he adds: "It is for the physiologist, not the chemist, to say what influence the admission of excrementitious matters into drinking water has upon the health of the community."

After such remarks, written by one who is held high among the leading authorities, what becomes of all our judgment in respect either to the analysis of ordinary drinking water or of that of the effluent resulting from any mode of treating sewage? Another instance of this uncertainty may be given. A sample of effluent derived from the A B C process was placed in the hands of five independent and able chemists. Their determination of organic nitrogen differed from 0.5 to 1.3 of a grain per gallon! It is evident, therefore, from what has been stated, that any attempt to determine the purifying results, in a sanitary point of view, regarding any existing method of sewage treatment, is comparatively valueless so far as indicated by chemical analysis alone. Taking the nearest approximation to truth that we can supply in regard to the potential effect of the A B C process on sewage, the following results may be relied on, gathered from about fifteen months' experience at Leamington, and three months' at Leeds, the examination analyses, etc., having been made daily. At no period, between May, 1870, and July, 1871, was the effluent of a daily flow of about 500,000 gallons at Leamington fit to run safely into a stream that might subsequently be used for drinking purposes, except at rare intervals, whose occurrence was accidental. The average effect, ascertained so far as possible, was that the A B C removed about 26 per cent. of organic and inorganic matters. But as, however, during that period a considerable addition was made to the amount of inorganic matters by the use of ammonia-alum, it would

* Blue book, No 99. March 11, 1872, page 37.

be perhaps right to state that about 38 per cent. of soluble and suspended matter of all kinds was removed. The result here given is deduced from about 150 analyses made at a time when little or no rain fell, in fact, during the great drought that prevailed in 1870. As regards the *appearance* of the effluent during that period, a depth of from 6 in. to 12 in. was sufficient to obscure vision of a non-metallic object. It must be repeated that the Leamington sewage was always rich in animal matter, and consequently produced a manure of a quality greatly superior to any that the A B C process has extracted from any other sewage, a point with which we shall subsequently deal in its commercial and chemical relations.

In regard to the effluent produced at Leeds, in quantities varying from 250,000 to 1,000,000 gallons daily, it may simply be repeated that when the entire arrangements were properly at work, the effluent could with difficulty be distinguished from the ordinary water supply. The total amount of organic nitrogen has been reduced to one five millionth part of the quantity analyzed. It has been drunk, by parties unaware of its source, under the impression that it was drawn from a newly discovered spring. The Leeds authorities placed samples for analysis in the hands of eminent chemists, and consequent on their report have resolved to adopt the process for the treatment of the whole of the sewage, amounting to about 13,000,000 gallons daily. So far results seem decidedly in favor, *under the circumstances named*, of the A B C process. It will be desirable, however, to investigate the financial details, as regards the production of such an effluent, and the value of the Native Guano as a commercial product, matters which will be considered in a succeeding article.

A NEW SYSTEM OF CHEAP TRANSPORT FOR SIDE OR TRIBUTARY RAILWAY LINES.

By WM. B. HYDE, C.E.

Cheap land transportation is a desideratum toward which the economists of nations have directed their best energies from the days of the first inception of wheeled vehicles down to the present. Running through the entire range of inventions and improvements, from the ox-cart to the railway and equipment, we find the demand still unsatisfied, a great void still existing and commodious transport facilities still out of the reach of any but heavily combined capital. The demand for facilities that shall be within the reach of hundreds of thousands of dollars instead of millions; that can be effected by a local community instead of a national combination of capital, is still far in excess of any available means of supply, and invention is still earnestly occupied in seeking such a solution or combination of the forces of Nature as shall reduce by many grades the expense of construction and maintenance of roads of transport. In the decade in which we live, we find through public expression a livelier and more intense interest in the actual development of this question than ever before. From all countries where steam has a home the same demand arises—cheap and efficient railroads or roads to be operated by steam, which shall require a minimum handling of the articles transported! Upon that text we have the present widespread agitation of the economic advantages of the system known as the "narrow gauge," an agitation from which we can judge of the importance of the subject when we recall that it is as rife in Russia as in England, in Sweden as in France and Germany, in India as in the United States. The system is now passing through the criticisms of the engineers and capitalists of all these countries, and so ardent is the hope that railways can be cheapened thereby, that in all the countries named, special lines have been or are being built to solve the knotty question within the crucible of practice. To meet the same imperative demand there is also proposed the French single rail or Lamarjat system, which in substance is the use of a single ordinary rail upon which run double-flanged wheels placed fore and aft of a rail carriage or engine, performing a guide duty, while the weight of car or traction of engine is sustained by wheels running on the hard Macadam road, or board or plank roads along each side of the rail. Again we have the Hodgson's wire rope tramway system—a moving wire rope

suspended on poles and carrying in suspension to the lengths between the supporting poles, boxes, bags, buckets, or anything which should be able to transport the packages of stone, goods, or any material desired. Several of these are in use in England and are proposed for other countries, and their use must unquestionably fill a gap that railways can never occupy. Finally we have the modern steam road wagon with its rubber tire, giving a tractive force of enormous extent and capable of a development of vast importance to the community. In all of these plans or systems one great radical defect appears, viz.: break in the continuity of movement of goods, or, as expressed by railroad men, "break of gauge." The vital importance of this continuity cannot be dissolved even by the intense heat of "narrow gauge" advocates, or the enthusiastic exponents of the steam road wagons. It is an importance which has made nations crown with their commendations the boldness of Ferdinand de Lesseps, in his destruction of the Suez barrier to the circling of the globe; it is an importance which has incited the profoundest economists and thinkers of modern times to grapple with the chains of Central America and strive to tear them so far asunder as to permit ships to shorten passage from the Atlantic to the Pacific, and while saving time increase the value of their services just so much; it is an importance most fully appreciated by our neighbors on the great lakes when their efforts finally clear the way for the passage of a ship with cargo untouched from Europe to Chicago; it is an importance which has made nearly all of the railroads in the United States of uniform gauge, and caused the vast river barriers of the entire country to be bridged at the cost of millions, rather than submit to goods transfer; and finally I may say, that it has an importance so paramount that all schemes, plans or systems proposing to cheapen transportation, must look well to it that other advantages are immensely predominant before feeder lines are made of broken gauge. To the hundreds of millions of capital now invested in uniform gauge lines in Europe and America, the subject needs no advocate; to the thousands of inventive minds in all countries continuity of gauge cannot be too strongly urged, and although I am an advocate of extreme narrow gauges in mountainous countries, where any other system might be ruinously expensive, it is to direct attention to the practicability of construction of cheap roads upon the present standard gauge of Europe and America, and not fritter our strength upon plans requiring entirely new equipment from end to end, and a constant ceaseless and finally intolerably vexatious transfer of every pound of freight going or coming, that these pages are written.

THE ROAD BUILT FOR THE LOCOMOTIVE AND NOT FOR THE LOADS.

In a recent number of the Chicago "Railway Gazette,' from an article on "Principles of Tractive Power in Locomotives," I quote the following, as showing in few words the present difficulties attendant upon much cheapening of any railway line:

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"The grand objection to any increase of the weight of our engines, as now constructed, is that it is too destructive to the track to load each pair of wheels *even as heavily* as is ordinary now. The blows dealt by passing wheels upon the rail joints, and the bending or breaking strains brought at any instant upon the joint in the rail where a wheel presses, depend upon the weight which the wheel carries as well as the speed at which it moves, and hence to diminish our track repairs, that which is nearly or quite the most greedy of all maintenance accounts, *the load borne per wheel* in our locomotives must be lessened one-half, so that it may more nearly agree with the load borne per wheel in the cars. How this can be done without increasing the rigid wheel base, while the present boiler and cylinder capacity are retained, is one of the most trying problems of the present day among locomotive builders, and certainly the most promising commencement of its solution is the introduction of the Fairlie engine, nothwithstanding the numerous complications with which it is still beset."

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To the locomotive builders of the country the principles of the Fairlie system are well known; sufficient to say here that it is but the application of the well used and known American bogie system to an engine; making each bogie an engine in itself, and thereby utilizing all of the weight of the engine for adhesion. Except in the fact of using but one fireman and engineer for a double engine, the application of that principle of total weight applied for adhesion, is common to innumerable tank engines in

the United States, which linked back to back would with equal weights give equally good results at the end of any given time of actual running, including necessary lost time for repairs. In the manufacture of his engines, Fairlie, without doubt, fully appreciated the magnitude of the very obstacles to cheap construction that are mentioned in the extract given above, but as far as developments are yet made, he has only temporized with the difficulty, and approached not one whit nearer the solution than many of our own American builders. From an article on the Fairlie engines, from an English Magazine, and published in convenient form for reference in the "Ramapo" Carwheel hand-book, the following will illustrate with still more clearness the motive of Fairlie's efforts and inventions, in sympathy with which are all seekers after cheaper transport lines: "One of the worst features in the present construction of railways is, that while the weight on each carwheel is from 2 to 3½ tons, the *whole line* must be planned for from 5 to 7 tons per wheel, although this weight is carried on but 4 to 6 wheels (engine) of the 168 wheels of an ordinary train of cars." Following this are descriptions of four types of engines: freight of 60 tons on 12 wheels, passenger of 40 tons on 8 wheels, freight of 40 tons on 8 wheels, and very light passenger of 24 tons on 8 wheels. This will give for his freight 5 tons per wheel, as against 2½ tons per wheel for the cars behind, and for his passengers, 3 tons per wheel. But what matters it that a very light passenger engine under this system has but 3 or even 2 tons per wheel, when his effective freight engines have 5 tons? The road must be built for the one 5 tons weight, although every other engine in the shop were but 2½. These illustrations will suffice to show the real difficulties in the construction of very cheap lines, which would have but a small fractional part of the work of a parent trunk, and hence to exist, must be light, cheap, and yet afford all necessary facilities. In passing, it will be well to show that the same difficulties beset the "narrow gauge" system, and in illustration therof, taking again a Fairlie engine, the now widely known and widely heralded "Little Wonder" of 1 ft. 11½ in. gauge, we find on English authority, that her weight on 8 wheels is 19½ tons, making 2.43 tons per wheel; while the work is done by passenger carriages loaded of 4,800 lbs. on 4 wheels, or 3-5 of a ton per wheel, and by light slate or coal trucks of 1,700 lbs. weight, carrying 6,000 lbs., total of 7,700 lbs. on 4 wheels, or, say 1 ton per wheel. The road upon which this engine operates, the Festiniog, in Wales, requires for this engine service, double-headed rails of 30 or more lbs. to the yard; whereas a strip of metal ¼ in. thick and an inch wide well laid on a longitudinal wooden sleeper, would be sufficient to sustain all the wear and tear of such wag ns or cars as are there used. Truly, the "Little Wonder" should cease to be such when we recall at what Mr. Fairlie aims with his engines, and how far he falls short with both broad and narrow gauge stock.

Speed has heretofore played too prominent a part in the consideration of cheap line plans; low speed for nine-tenths of the freight tributary to a trunk line would be far more preferable to the producers and consumers in a country if it could be accomplished at $6,000 or $7,000 per mile of line, than higher speed at $15,000 or 20,000 per mile. A very large share of the freight to be carried on our California outlying roads, would be fuel, lumber and grain, for which a steady movement of 5 miles an hour would be abundant, until it should have reached a trunk line. Passengers in like localities can be well served at 10 miles an hour, provided, the same be regular, steady, and at low rates. Low speeds mean very much reduced wear and tear, and hence ability to use much lighter rails and fastenings, and where necessary, lighter rolling stock, and it would seem that all engineers should unite in support of that one element in consideration of systems of cheap subordinate lines. As an illustration of its effect, it can safely be assumed, that with a strengthening comprised within an expense of $100.00, our ordinary street cars, with their fair complement of *seated* passengers, could regularly perform duty at 10 miles an hour, with safety and economy, and the bearing of this upon the purchase of passenger rolling stock, can be readily seen: Again an ordinary 4 ft. 8½ gauge flat car loaded with grain, making, say, a gross load of 18 tons on 8 wheels, or 2.25 tons per wheel, will require very slight rail accommodation to sustain it at speeds of 5 miles an hour. In the Eastern States, the demands of farming communities are analogous to our own. In mining districts the same rules hold good: the

delivery of ore, or timber, or fuel, at 10 miles an hour, as compared with 5, offers no equivalent advantages to the increase of first cost in all the essential elements of construction.

Having directed sufficient attention to the facts of our present system, showing that our roads are necessarily made to accommodate the great strains from the locomotives, instead of lesser ones from the cars, and that a continuance of this system by either broad or narrow gauge side lines, must necessarily keep up the cost of such enterprises, I shall here point out the plan I have in view, by which an unbroken gauge can be carried from any trunk line direct to the centre of a farming or other producing community, and at costs proportional to the work to be done, and not exceeding $6,000 or $7,000 per mile in our valley counties.

We require a railway which shall be able to safely sustain loaded freight cars from the parent road, at speeds of 5 or 6 miles an hour, and a special class of very light passenger cars, at speeds of 10 or 12 miles an hour, and a locomotive power so disposed as to haul the above without demanding a 45, 56, or 60 lb. rail for its service.

To accomplish this end, I propose that very slight roadways be built as near the surface of the ground as possible within grades of 200 ft. per mile, and with a superstructure of ties of 2½ in. by 8 in., by usual length, surmounted by longitudinal rail stringers of straight Oregon pine or other good wood of 3½ in. by 6 in. deep, surmounted by a good strap iron, with ends spliced by an underneath fish-bar let into the surface of the wooden under-rail and bolted entirely through the same. With such a rail, the work which I have enumerated above can be easily and safely done. Between the rails I construct a strip of flat roadway 18 or 20 in. wide at top, and which is about flush with the plane of the side rails. This strip to be manufactured of any material cheapest to the country in which the same may lie, be it stone or wood, asphaltum or Macadam. Upon this centre strip of roadway will operate a broad elastic tire traction wheel, having just sufficient weight of the engine resting upon it to utilize every pound of steam that the cylinders receive from the boiler, permitting the remaining weight of locomotive to be so distributed by truck wheels as to bear upon the track very lightly and afford guidance to the locomotive. I make the centre strip of equal heights with the side rails, so that at all junctions or switches the traction wheel can traverse without obstruction from one track to another. By this plan, the individual elements of which, at different times, have been considered by inventors, but which, by a new combination, I think affords a system upon which the very minimum expense will produce a maximum return, there will be nothing really new but the type of locomotives proposed, which is not so expensive by a large percentage as the Fairlie innovation, and affords a much greater power in proportion to its weight. The present condition of our locomotives in having from four to five times as much weight upon the drivers as can be utilized or reproduced in adhesion, is completely changed by making the enormous tractive power of the central wheels the recipient of sufficient weight to use up *all the steam*. In other words, an ordinary 30-ton engine with 20 tons on drivers, gives a traction force from adhesion of not over 12,000 lbs., or 600 lbs. per ton. With the same weight on two or more elastic tired traction wheels on dry surface of centre strip, with effective traction of 1,600 lbs. per ton of weight, we should have a total traction force of 32,000 lbs. at the rails, but obviously the engine and boiler power of an ordinary 30-ton locomotive is insufficient to use all that adhesion, though more than sufficient to use up the adhesion of the former wheels; hence we can gauge the weight, whence the traction, upon the central wheels by the power of the boiler to use it, and not waste afterwards a pound of steam. We have thus a way open by which, for low speeds, a very light engine can be made to accommodate all the traffic of ordinary side lines and switch its own cars with ease and safety from trunk to tributary, or *vice versa*, and also to run at the stated passenger speeds without pounding the side rails to pieces or wearing the centre strip away by friction. The central wheels or wheel being elastic, the tire will at once throw into a really effective use their enormous tractive powers, now known by repeated trials to be possessed with hard and even road surfaces. The facts are abundantly settled in Europe, that upon hard paved roads or ways, the rigid wheel is much inferior in tractive powers to those of opposite tires, and in the trials and trip recently made by the steam wagon manufactured in San Francisco, it

was found that the wheels on any hard substance could not be slipped by the entire power of a 30-horse engine concentrated on one wheel, its "bite or grip" upon the ground being so great, and in a close study of the capabilities of that wheel the present plan for its most advantageous use was resolved, finally leading directly to a system which, it is thought, by means of the traction locomotive will go far towards cheapening rail transportation and obviate any necessity to break gauge wherever such break would be undesirable. In a populous side country requiring moderately frequent passage of loaded freight cars from a main trunk, side rails of 25-lb. iron, with the traction roadway between, would be admissible, and even then be inferior in cost per mile to the narrow gauge connections for the same services. In a less demanding farming country, where the greatest work would be a daily train delivering the grain or cattle production of the season, the superstructure made as hereinbefore suggested, with wooden side rail and iron surface strap, would be abundantly sufficient; and for a small community of farmers with freight and general business sufficient to warrant an expenditure of $3,000 per mile, for a way to bring the freight cars of a great trunk road to their doors, a similar wooden side rail with a surface strip of well-selected and *artificially preserved wood* will offer every requisite strength for the work required of it, and be as durable under that work as the strap rail divisions would be under the increased work demanded of it, or even as the main trunk line and heavy rails compared with the work required of it. In all cases the light traction locomotives built to haul freight cars at low speeds, can receive from a passing train, on any trunk, the cars intended for the side districts, and can successively traverse the different sections of the cheap roadway here proposed, delivering goods to the merchants' doors. and in return receiving cars loaded, perhaps, from the very orchard of a producer, deliver those cars with the fruit bloom unmarred, to the passing freight for delivery to city or overland. Grain shippers the same, and in short, the producer suffering from want of a very cheap yet sufficient system of transportation, can in this find outlet at cost easily compassed by himself and neighbors for all his productions. In dwelling thus at length upon the facility offered by this system for unbroken gauge between trunk lines and tributaries, its effect upon the actual first cost of a roadway is immediate, for the reason that in almost all countries the freight going to or coming from a main line will be handled by the cars of the main company, and hence save the purchase of any such rolling stock; no transfer depots need be made for the same reason; shop facilities need be very light, as with unbroken gauge a traction locomotive can be hauled to the nearest shop for needed repairs, paying for exactly what was done, without the maintenance of any expensive shop belonging to the lesser road. The freighting expenses upon the original materials for the lesser roadway not being rehandled from the cars of the main road, involve that much less expense. Many old roads have light engines, that at very light expense could have their present drivers removed and the same cylinder actions applied to one or more low traction wheels placed underneath the boiler, and thus producing a powerful light locomotive for the light line at moderate cost. The same saving can be maintained in many instances by the hiring, on an agreed mileage rate, of the light and often discarded passenger cars of a larger road. In roads where the terminal connection might be at navigable water instead of another and larger road, the using of the ordinary gauge will permit the rolling stock to be gathered in the first instance from different main roads in the State, and, in many instances, at costs far less than original and new stock, although the far greater cause for such adoption of gauge, of an apparently independent road, is found in the fact that no combination of circumstances in valley countries, or those moderately hilly, will obviate the probability of some final connection being made with other lines, and this, perhaps, demanded so imperatively as to exhibit again such a reconstructive phenomenon as shown recently by the Ohio and Mississippi road in their change of the original gauge of over 300 miles of road to 4 ft. 8½ in. in a *single day*. The great tractive power of the central wheels proposed will permit grades up to 200 ft. per mile to be used, which fact will largely affect the original cost of the earthwork and not affect seriously the after operating expenses, when it is remembered that in California, at least, a very large proportion of all freight movement on side

roads will be upon down grades towards water or a larger road.

At San Francisco prices, ordinary gauge side lines upon this system, can be constructed with necessary equipment, for, from $5,000 to $7,000 per mile. Whenever the difficulties of country actually demand a reduction of gauge to 3 ft. or 30 in., the same advantages obtain in every particular in favor of the locomotive system here proposed, over the ordinary plans for narrow gauges; and remembering, as shown in a former page, that even the far-famed Welsh railroad, with the Fairlie "Little Wonder," of 1 ft. 11½ gauge, is built to sustain a work of 2.43 tons per locomotive wheel, while the heaviest car pressure per wheel is not exceeding 1 ton, the cardinal advantage of throwing all the tractive weight of the locomotive on a broad inexpensive central strip, thereby reducing side rails to a size no greater than actually required for the rolling loads of the cars, is as prominently superior to the advantages of the Fairlie system, as in the broad gauge, and hence the system now proposed cannot be charged with being offensive to the "narrow gauge" except where its use will obviate all necessity of making a tributary of narrower gauge than a main line, by decreasing original cost to at least that urged as maximum for building fully equipped narrow lines.

With the central traction wheel, locomotive curvature becomes of less importance than with the Fairlie double bogie engines, for the driving power being on one or two central wheels, resistance to curvature deflection becomes exceedingly slight, and the lateral twisting of the engine in swinging around curves, cannot wear the central road-way, as that twisting is all absorbed by the elasticity of the tire, and not ground upon the road-way underneath.

We have only one other point to overlook with relation to the traction wheel: first, will it be durable with tire made of rubber? We must remember in this connection that many of the usual elements of wear and tear are by this system concentrated and put in one; as for instance, hammering of rails, wear and flattening of tires, shatter of machinery, all are concentrated in the *wear* of the elastic tire, so that, assuming that it should be condemned for service once a year, its cost will be far below the aggregate cost of the items now prevailing on our ordinary roads. Again the question of durability depends absolutely upon the *manner* in which the rubber is disposed, and hence used. The Scotch rubber tire, invented by Mr. Thompson, is a solid band upon a smooth wheel surface, the latter perforated with holes to assist the friction of the rubber to the wheel, and with the wearing surface of the tire protected by a chain of shoe plates, extending completely around the wheel. The action of this wheel when under the severe strain of hauling loads, is such that, the tire being compressed, the rubber is constantly *stretched* on one side of the point of wheel contact, and fulled or compressed on the other. The wheel patented by Mr. Oliver Hyde, of California, operates under an entirely different principle. The tire is formed of a succession of round or cylindrical solid rubber springs, laid across the face of the wheel; the angle between the curve of the cylinders being filled by raised angles being a part of the iron surface of the wheels. The rubbers are kept in place by similar angle plates, with pendant sides, on which are projecting side lugs, which around the wheel are encircled by a solid metal ring, made fast to the wheel, holding the tire firmly together. The rubbers being separated when in action, the angular plates receiving the pressure, press in against the rubbers, and are resisted by the compressive power of the rolls; and these rolls at every new revolution of the wheel, revolve slightly on their own axis, hence presenting an entirely new line of the rubber to compression, in this way insuring the uniform wearing of the rubber; said wearing and work resisted by its strongest element, that of compression, reinforced by the individual revolution of the rolls, by the presentation of an entirely new fibre at every strain, as the wheel revolves. This wheel has been most severely tried in California and Utah, and its wearing resistance and free working capacity most carefully tested, and the more severe the strain put upon it, the more firmly do the rubbers crowd themselves into the periphery of the wheel, and against the filling angles of its surface. The great difference in the principles involved in the two wheels, has instituted close comparison, and for traction-power, and durability, and superior economy in first cost, the California wheel is already occupying a favorable position, as compared with the Thompson.

In submitting this sketch of a proposed system of cheap roads, which shall be

thoroughly efficient for purposes intended; a system which, by the very nature of the principles involved, can be constructed per mile at less cost than any other yet proposed, I have descended to details of construction only so far as has been necessary to illustrate the subject, feeling confident that, if favorably received, the genius of our American engineers and locomotive builders will compass all details, so that the object aimed at, cheap construction for moderate capital, will be abundantly obtained.

To the capitalists, engineers, farmers and producers generally, of our State, this system is here sketched out and submitted. I have labored to go to the root of the difficulties attending very cheap construction of railways for side lines, and then have endeavored from that root to build up a newer system; effective, simple, cheap, and yet which, in its various elements, presents nothing so new as to startle conservatism, but, by a new combination of those elements, enables us to see the way towards the great desire of the political economist, and lover of positive progress: Cheap transportation facilities.

TERRESTRIAL MAGNETISM.

By Rev. J. S. PERRY, F.R.A.S., Director of the Stonyhurst Observatory.

From "Nature."

In bringing before you this evening, gentlemen, the subject of terrestrial magnetism, it is not my intention to attempt to present you with an exhaustive paper on so wide a subject. It would be idle to pretend to give in a few short pages an adequate idea of all that has been ascertained on this subject, or even to present a satisfactory historical sketch of the progress made from earliest ages to the present time. Nor will I trouble you with a bare enumeration of the many facts, and methods, and theories that have gradually led scientific men to their present knowledge in this matter. But I will try rather to state, as clearly as I am able, what is the actual condition of our knowledge respecting the magnetism of the globe, and what the nature of its complex variations, without, however, entering much into details, which, though they might perhaps be most convincing when reviewed at leisure, would be entirely out of place here, since they would only serve to encumber a paper intended for public perusal.

But, before treating of the special subject of terrestrial magnetism, allow me briefly to recall a few of the well-known properties of magnets.

That certain bodies possess the power of attracting iron was not unknown to the most ancient people; and men who had noticed this could not long have failed to observe the disturbing power that iron, in its turn, exerts upon the magnet when brought into its immediate neighborhood.

But the duality of the magnetic force was doubtless a discovery of much more recent times, though now equally familiar as the former. That this twofold force ever seeks the opposite extremes, or poles, of a magnetic body, and that these poles, whilst possessing alike the power of attracting iron, are diametrically opposed in their action upon the poles of any other magnet, is expressed in the trite law that, "likes repel, and unlikes attract." Again, the law of magnetic intensity was unknown until the middle of last century, when it was was found by Michell to be identical with that of universal gravitation, namely, to diminish inversely as the square of the distance of the body attracted. That this was not discovered at an earlier date is partly due to the complexity of the phenomena arising from the duality of the force, combined with the inseparable nature of the two energies. For, unlike electricity, to which in most other points it is so near akin, neither the positive nor the negative element of magnetism can ever exist alone in any body.

Now, since we know that magnets and iron act mutually upon each other, and that one magnet attracts or repels any other according to certain fixed laws, if we remove all disturbing bodies from the vicinity of a magnet, and leave it perfectly free to move by floating it on a liquid, or suspending it by a thread, we might expect to see the magnet remain at rest in whatever position we place it. But we perceive at once that this is not the case, and the magnet we thought to be free is found to be subject to a directive power, which forces it to take a

fixed direction without in the least interfering with the position of its centre of gravity. Disturb the magnet, and when it comes to rest it will again lie in the same direction as before. The earth, therefore, exerts a certain influence on the magnet, not producing any translation from one position to another, but only forcing the poles of the magnet to assume a definite direction. That this power possessed by the earth is precisely similar to that of an ordinary magnet, is easily shown by counteracting the earth's action by means of a magnet, placed at a suitable distance from the free magnetic needle, and with its marked end in the same direction as that of the needle; the latter will then rest in any position in which it is placed.

This polarity, or directive power of the earth, is said to have been known to the Chinese 1,000 years at least before the Christian era, and to have aided them in their long journeys across the trackless wastes of their vast empire. The use that has since been made of this simple fact, the growth of commerce, the spread of civilization, and the thousand other blessings that it has brought to our very doors, need no long comment here. We may well marvel that such a source of wealth and prosperity was allowed by mankind to remain almost fruitless during such a long succession of ages.

The horizontal direction taken by the freely suspended needle is nearly north; but it generally deviates somewhat from the astronomical meridian. This deviation is termed the declination or variation of the compass. The existence of the declination was not unknown in remotest times, although its discovery is sometimes erroneously attributed to Christopher Columbus. To this great man we are, however, indebted for our knowledge of "the variation of the variation," since he was the first who noticed its change as he altered his geographical position in his great voyage of discovery across the Atlantic.

The first and most important fact in terrestrial magnetism, viz., the declination or horizontal lie of the freely suspended magnet, being established, we may take an unmagnetized piece of iron, similar in weight and form to our magnet, and balancing it on an axis passed through its centre of gravity, allow it to rest on the extremities of this axis. We shall find that the unmagnetized needle will remain at rest in whatever position we choose to place it, since we have taken care to suspend it by its centre of gravity. But if we now substitute the magnetized instead of the unmagnetized needle, and place it in the plane of the horizontal magnet, we shall perceive at once that at whatever angle we place it on its supports it will invariably take up a definite position with respect to the horizon, the marked end, which points W. of N., dipping down until it stands in this country at an angle of about 70 deg. to the horizon. The earth, therefore, not only tends to bring the magnetic needle into a certain azimuthal plane, but it also forces it to take a fixed position in that plane. The direction of the magnet is thus wholly determined by the earth's magnetic force.

Our next care will, therefore, naturally be to discover, if possible, what is the intensity of this terrestrial force which acts upon the needle. This might be determined by finding the resistance it is capable of overcoming, or the weight it will balance, the weight being attached to a thread wrapped round the axis of the needle. But the intensity of the earth's pull is more accurately found by a method similar to that which has been used with such success in observing the force of gravity at different points of the surface of the globe, in view of ascertaining the amount of its compression. A magnetic needle is suspended by a thread, from which all torsion has been removed, and then an oscillatory movement at right angles to the plane of minimum dip is imparted to the needle in such a manner as to leave the point of suspension at rest. The square of the time of a single oscillation is a sure measure of the intensity of the force producing the vibration, which in this case is the product of the magnetism of the needle by the horizontal component of the earth's magnetism. The factor due to the magnetic strength of the needle can be eliminated at once if the power of our needle is known, and the horizontal component of the terrestrial magnetism divided by the cosine of the dip of the needle will then give the required total intensity. But if the power of the magnet is unknown, and on account of slight but continual changes, it is always safest to consider it as doubtful within certain limits, the quotient of the earth's horizontal force by the magnet's power can easily be found by measuring the deflection of a free magnet produced by the attraction of the vibration needle at given

distances. The result of these experiments is to place in evidence that the intensity of the earth's magnetism follows laws as constant as those of its directive force.

Having thus made curselves acquainted with the three essential elements of the magnetism of our globe, viz., the dip and declination, which determine the direction, and the third, which expresses the intensity of the attracting force, our next step in the study of the earth's magnetism, as a whole, is to secure the most trustworthy observations of these three elements at as many different stations as possible. The instruments used must be of the most delicate description, as the differences to be measured are often excessively minute. For this purpose the needles are suspended by the slenderest thread of unspun silk, or the smoothest axis rests on knife edges of polished agate. The care with which the observations have to be taken may be judged of from the fact that, to obtain the time of a single vibration of the needle, 12 sets of 100 or 200 vibrations are taken, and each estimated to the 20th of a sec.; or, again, for a single observation of the dip, the needle, which is balanced by the maker with scrupulous care, is so far suspected that readings are taken of each end, the needle is turned on its Ys, the whole instrument is reversed, and finally the poles are altered, and each of these readings repeated at least twice before the observer has satisfied himself that all necessary caution has been taken to secure a perfect observation. An apparatus of greater delicacy than those in general use has lately been invented by Dr. Joule, of Manchester, which we may hope will furnish results of still greater accuracy than those already obtained.

It was not until towards the middle of the sixteenth country that accurate determination of any of the magnetic elements were attempted; but since that time the declination has continued to be observed with some regularity, and before the end of the seventeenth century Halley had already made two long voyages to observe this element at different parts of the globe.

The dip, whose discovery is due to Norman, was first observed in 1576; but it does not seem to have attracted much attention until two centuries later.

The determination of the intensity, by means of the vibrations of a magnet, was first suggested in the last century by Graham, and the first maps of the isodynamics, or curves of equal intensity, are the fruits of the labor of General Sir Edward Sabine, who is now devoting the declining years of his life to the publication of the results of his life-long study of terrestrial magnetism.

From the above observations of the three magnetic elements, taken at different positions on the surface of the globe, the first general conclusion we are able to draw is one of no little importance. For, starting from any point of the earth, and following the direction of the horizontal needle, we are invariably led to one or other of two points, situated respectively in the Northern and Southern hemispheres. The entire globe is, therefore, traversed from N. to S. by a system of magnetic lines, all meeting in the same two points, resembling in this respect our geographical meridians and poles, and therefore termed the magnetic meridians and the magnetic poles of the earth. Our second conclusion is of scarcely inferior importance to the first. For if, instead of following the direction of the horizontal needle, we carefully observe the dip, and travel along the line, where we find the inclination invariable, we shall always be led, not up to a magnetic pole, but in a more or less circular path around the pole. These curves of equal dip, generally called isoclinals, bear a close resemblance to our geographic parallels of latitude; and as the geographic latitude varies from zero at the equator to 90 deg. at the poles, so in like mannner the dipping needle, which is horizontal at the magnetic equator, gradually increases its inclination until it becomes vertical at the magnetic poles.

From these angles of position of the dipping needle we can conclude at once that the horizontal component of the earth's magnetism must be zero at the poles, and probably maximum at the magnetic equator, where the terrestrial force is wholly horizontal.

We may, therefore, describe the magnetic poles in the words of the Astronomer Royal, "as the common points for the convergence of magnetic meridians, for the verticality of the dip, and for the evanescence of the horizontal force."

But there are other points on the earth's surface which merit our most special attention. I will not call them poles, as they have little in common with the two poles of which we have just been speaking, but I will describe them as points of maximum intensity. The isodynamics, or lines of

equal intensity, are not found to follow such simple laws of distribution as the meridians and the lines of equal dip and horizontal force, though these latter are far from being arranged with the same regularity as the meridians and parallels of latitude of a geographic globe. None of the magnetic curves are perfect circles, the poles are not coincident with the geographic poles, nor are they opposite to each other, one being situated north of Baffin's Bay, and the other in South Victoria; but still there is a general approach to regularity in the magnetic lines, if we except the isodynamics, and the law of variation of the dip was found to be fairly represented by the formula, tan. $\delta = 2$ tan. L (the magnetic latitude), a law discovered by Krafft in 1809. The greatest departure from the general regularity of the curves we have been mostly considering, is the indication of a second pole in the Southern Hemisphere from the peculiar distribution of the lines of equal horizontal force. But in the case of the isodynamics we find three well-marked points of maximum intensity: one N.W. of Hudson's Bay, another in Siberia, and the third not far from the South magnetic pole in Victoria. Besides these there are also two maxima of small intensity, one situated slightly north, and the other at about 15 deg. S. latitude. We are still, however, able to trace a rough approximation to a law in the change of the intensity, the value at the principal maximum being about double what is found to be on the curve of minimum intensity.

The distinction between points of maximum intensity and the true magnetic poles has not always been attended to with sufficient care, and this is partly to be accounted for by the considerable and often preponderating influence of these maximum points on the several magnetic elements. A consequent doubt was for a long time entertained respecting the number of the magnetic poles. Halley, from a careful study of an extensive series of declination observations, made partly by himself in 1698–9, was led to the conclusion that the earth has four magnetic poles. The same opinion has been most ably advocated within our own days by Prof. Hansteen of Christiana, who had previously collected together a vast mass of observations of the declination, dip, and horizontal force. But the interesting series of results which Hansteen has brought forward in support of his view, are most readily explained by the evident changes that have taken place in the magnetic state of the region of maximum intensity situated in Siberia, where Hansteen himself specially observed. The Northern regions, where the magnetic force is greatest, abound in ferruginous strata, and there too the intensity of the cold far exceeds anything that is experienced in other lands on the same parallel of latitude. These regions may therefore not only be charged with a most abundant supply of permanent magnetism, but they may also be affected to a very considerable degree by atmospheric changes, and by those electric currents that are continually passing to and fro in the upper crust of the earth, and are doubtless producing very important changes in the subpermanent magnetism of certain layers of softer ferruginous matter. Whatever may be the nature of terrestrial magnetism, we cannot ignore the great influence exercised on its distribution by what may be termed local magnetism, the magnetism of volcanic formations, of mountain chains, of ferruginous beds; some harder than others and therefore less subject to magnetic influence, but retaining its effects the longer; some more affected by the extremes of heat and cold, and hence exposed to more rapid and radical changes in their magnetic condition.

But the question of the number of magnetic poles is leading us to another point of scarcely less importance, viz., the investigation of the changes that take place in the magnetism of the globe. The first point of inquiry is whether terrestrial magnetism as a whole is subject to continual change, and if so, are these changes periodical? Do they move in cycles? Do they follow any fixed laws that may lead to a knowledge of their causes?

The difficulty in answering these questions arises mainly from the irregular distribution of the points of maximum intensity; but, granting that we meet with numerous exceptional cases, which no doubt will finally be discovered to depend on local influences, we can trace a very regular and periodic change in all the magnetic elements.

The first accurate observations that have come down to us are those of the declination, or variation of the compass, taken in Paris in 1541, when the needle pointed 8 deg. to the east of the astronomical meridian. From that period the easterly

deviations gradually increased, until it attained a maximum value of 11 deg. 30 min. in 1580, when it returned slowly on its path and vanished in the year 1660, Paris being then on the curve of "no variation." Pursuing its westerly course, the needle pointed more and more west of north each year, and only reached its greatest western elongation of about 23 deg. in 1814. The needle is at present returning towards the east, at the yearly rate of about 9.5 min. and actually points rather less than 17 deg. west of north. The variations of the declination at London have followed much the same order as those at Paris, nor has there been any great difference in the extent.

The dip observations have unfortunately not been carried on so continuously during such a long series of years, and in consequence the secular variation of this element is less well determined than that of the declination. With the exception of a single observation by Norman in 1576, who found the inclination of the needle at London to be 71 deg. 50 min., we have scarcely any reliable data previous to 1720, when the dip had increased in London to 74 deg. 42 min. Since the latter epoch this element has always continued to decrease, being 70 deg. 35 min. in 1800, and now less than 68 deg., with an annual diminution of about 2.5 min.

Of the secular variation of the intensity we know even less than of that of the dip, since the first observations date only as far back as the end of the last century; and we have no less an authority than that of Sir Edward Sabine for the statement, that "at the commencement of the present century the bare fact of there being any difference whatsoever in the intensity of the magnetic force in different parts of the earth was unattested by a single published observation." The results, however, of modern research supply us with the important fact that the horizontal component of the intensity is at present rapidly increasing, its yearly rate of change being one 600th of its total value.

Now each and all of these gradual variations in the several elements of the earth's magnetism force upon us the conclusion that the magnetic pole must be endued with a motion of rotation in a more or less circular path around the pole of the earth's axis. The results of such a rotation apparent to an observer situated for example in England, will be easily understood if we consider for a moment the similar movement of any of the inferior planets in its orbit round the sun as viewed from the earth. Take Venus, for instance, which is the most conspicuous of the planets. At one time it may be seen moving away from the sun towards the east, when it is called the evening star, since it sets later than the sun. This outward movement continues for a time, until the planet reaches the point of its maximum elongation; it then returns toward the sun, and after a time becomes lost to sight in the brilliancy of the solar rays, or on very rare occasions is visible in transit over the solar disc, as it will be for the first time this century in 1874, and again in 1882. Having passed the sun Venus becomes the morning star, rising earlier and earlier until it has attained its greatest western elongation, when it again returns towards the sun. An analogous movement of the magnetic pole around the geographic pole has been clearly indicated by the secular variations of the declination, dip, and horizontal force. At the middle of the 15th century the bearings of the needle which would lead us to the magnetic pole were some 10 deg. east of north. As time went on, this deviation diminished, whilst the dip increased, showing that the magnetic pole was approaching us, as it got nearer and nearer to the meridian. About the middle of the 17th century, or rather somewhat later, the magnetic pole crossed our meridian, which thus for the moment partly coincided with the "line of no variation." From that time the needle has always pointed west, the western declination increasing more and more until the pole reached its maximum elongation in 1815. During this period there was a gradual decrease in the dip, manifesting a recession of the pole, and this has continued steadily, though with diminished acceleration, ever since the needle commenced its backward journey towards the geographic meridian. The present secular increase of the horizontal force also shows that the pole is receding, and that it will cross our meridian next on the further side of the geographic pole. This will take place, according to the calculation of M. Quetelet, Director of the Brussels Observatory, about the year 1940, and thus a complete revolution of the magnetic pole will occupy a period of some 560 years. Other physicists make this period longer. Local magnetism must of course interfere

greatly with the position of the pole, and with its velocity of revolution; but this disturbing cause will affect still more the movements or form of the "curve of no variation."

This rotation of the magnetic pole round the extremity of the earth's axis bears so striking a resemblance to the motion of the pole of the heavens round the ecliptic, that we are led at once to inquire if anything can be detected in the magnetic rotation that corresponds with the inequalities in the precession of the earth's axis, with the nutation caused by the action of the sun and moon. Are there, in other words, any annual, semi-annual, or monthly inequalities? The observations of the declination, taken during a series of years, and grouped together according to months, led to a variety of conclusions respecting the influence of the sun on the deflection of the needle. Arago agreed with Cassini in placing the sun in the vernal equinox at the maximum western variation, and in the summer solstice at the minimum; whilst Bowditch, in America, and Beaufoy, in England, both found that a maximum occurred in August and a minimum in December, though a second maximum and minimum were placed by each in different seasons. The fact of some yearly range of the needle about its mean position appeared to be established; but local influence seemed to have a large share in determining the nature of the annual curve.

The problem was attacked later on by General Sabine in a much more definite manner, and with much greater chance of success. The earth, as we are all well aware, moves round the sun in an elliptic orbit, the nearest approach of the two bodies occurring at about the time of the winter solstice; if, therefore, there be an annual inequality it will probably attain its maximum when the earth is in perihelion, and its minimum at aphelion, since the magnetic force is known to vary inversely as the square of the distance. The year was, therefore, divided by Sabine into two equal parts, and the mean of all the observations taken during the six winter months compared with the mean for the six summer months. The records of the three British Observatories of Hobarton, Toronto, and Kew, all agree in showing that the magnetic intensity of the earth is greater in winter than in summer. This was very satsifactory; but the same calculations have since been made for other magnetic stations, where monthly determinations of the three elements are carried on without interruption, and some of the results are far from confirming the above conclusion; for we find that observatories as near as Kew and Greenwich are in direct opposition on this point. A more extensive series of comparisons will finally show how far this disagreement depends on the accidental nature of the observing stations; but at present the preponderance of the evidence is decidedly in favor of a semi-annual inequality.

A similar investigation of the effect of the moon's action on terrestrial magnetism requires a series of observations made at much less distant intervals than the monthly ones, which suffice for the study of the annual variation. This new question presents itself to our view under a twofold aspect. The effect of the moon may be studied either in its independent action, or as it acts conjointly with the sun; in the former case we must group the observations with respect merely to the position of the moon in its orbit, and, as this is an ellipse with the earth in the focus, the force, varying inversely as the square of the distance, will have its maximum disturbing influence at perigee and its minimum at apogee The range also of the inequality will depend on the eccentricity of the orbit, and the period of variation will coincide with the siderial, or more strictly the anomalistic, month of a little over twenty-seven days.

But if we consider the moon as acted upon by the sun, receiving its magnetic power, as it does its light and heat, from the central body of our system, or merely having its own inherent magnetism modified by solar action, then we must choose as our unit the lunation, or synodic month of 29.5 days, observing the changes that take place as the moon approaches to or recedes from the sun. A careful sifting of the Greenwich observations led Mr. Airy to a belief in the existence of a menstrual inequality of the declination, attaining its maximum on the fifth day of the moon's age, and of a semi-menstrual inequality of the horizontal force, whose maximum occurs on the second day. The solar effect on the moon's magnetic power would, therefore, appear to be cumulative, and not to be fully developed till several days subsequent to the conjunction of the two bodies.

No examination seems to have been as

yet made to test the existence of a monthly variation due to the independent action of the moon, as the sole disturbing force.

The sun's rotation on his axis presents another not improbable cause of periodic magnetic disturbance. For if the sun acts as a large magnet directly upon the earth, and the poles of the sun's axis of rotation are not coincident with its magnetic poles, the rotation will present the solar magnetic poles alternately to the earth, and these acting singly, the result must be a synodic inequality, dependent on the period of the sun's rotation. The absence of any such irregularity is adduced, by a recent author on terrestrial magnetism, as a proof that the variations of the earth's magnetic force are due solely to the indirect action of the sun; but Prof. Hornstein has just succeeded in detecting in the magnetic records of Prague and Vienna an inequality in very close accord with the synodic period of the rotation of the solar spots. The magnetic period of 26 days 8 hours would give, as the true time of the sun's rotation, 24d. 13h. 12m., whereas Spörer, from the most accurate observations of spots near the sun's equator, found the time to be 24d. 12h. 59m. It becomes, therefore, probable that the sun has a direct magnetic action upon the earth; but this need not in the least interfere with the probability of its simultaneous indirect action by means of its thermal energy.

Having been able to detect, in the manner just described, the inequalities arising from the orbital motions of the earth and moon, we are immediately tempted to suppose that the diurnal rotation of the earth must also exert a not inconsiderable effect on the magnetism of any particular station on the earth's surface, and possibly even affect terrestrial magnetism as a whole. It is well known that change of temperature has a very powerful influence on magnetism, and therefore we should be astonished to find that the daily range of temperature induced no corresponding range in the earth's magnetic elements. The freely suspended magnet is the most delicate of thermometers, and consequently, unless we wish the diurnal variation of the earth's magnetism to be completely veiled by the more extensive changes due to the varying heat of the magnet itself, we must take the greatest care to keep the suspended needle in a locality not directly affected by the daily alternations of temperature. Attending to this precaution, by building our magnetic chamber at a considerable depth below the surface of the ground, we still find that there exists a most decided daily range in the motion of the magnet, to which the most delicate thermometer is wholly insensible. This daily range was detected by Graham as early as 1724, and a momentary inspection of nearly any two days' march of the suspended needle will suffice to make this point evident. The maximum west declination, about 2 P. M., is constant throughout the year, whilst the principal minimum varies with the seasons, as do also the secondary maximum and minimum. Canton has accounted for the leading feature in this diurnal change by the fact that the solar heat lessens the magnetic power of that portion of the earth on which it directly falls, and thereby gives a preponderating influence to the opposite portion, whose strength remains undiminished; the needle, therefore, moves towards the West in the morning, and only returns towards the East as the Western sun restores the balance of attracting forces.

But there are other variations of the daily range besides those just mentioned, for not only do most of the inflections of the diurnal curves alter their time with the progress of the sun in his orbit, but the amplitude of the range passes through a constant order of phases as each year advances. Dr. Lloyd discovered that the maximum range of declination in summer is greater than in win er, and Quetelet not only confirms this, but also finds that the range is greater at the equinoxes than at the solstices. It was whilst engaged upon this investigation that the Director of the Brussels Observatory made the curious discovery, that the magnetic energy varies in the same manner as the vegetable force, both attaining their maximum in April, and diminishing gradually until they reach their minimum of intensity in the winter months. Other observers, such as Lamont of Munich, Col. Beaufoy, etc., may be cited in confirmation of the existence of this apparent connection between the vegetative force and that of magnetism, a connection which may perhaps serve to throw some light on the nature of magnetic action. The horizontal force follows a law similar to that of the declination, varying in its daily range with the seasons, and attaining its maximum value in summer.

Another peculiar semi-annual inequality

in the diurnal variation has been detected by Mr. Chambers, the times of opposition being the equinoxes. This inequality is found to exist in the observations taken at seven stations—five in the northern, and two in the southern hemisphere. It only lasts from 6 A. M. to 6 P. M., reaching its maximum at 9 A. M. from January to June, at 3 P. M. from July to December, always passing through the mean value at noon.

If now we turn from the consideration of the effect of the earth's rotation on the direct solar magnetism, to examine its influence on that of our satellite, we are again led to expect a positive result, but on very different grounds from those we have just been reviewing. The heat sent to us by the moon, even when full, is so insignificant, that it is requisite to collect the rays in some enormous mirror, such as that of the Earl of Rosse, or to bring them to a focus on a very sensitive thermometer, in order to make it sensible. It would be absurd, then, to look for any effect that the rotation might produce in the variation of the temperature; but it is very reasonable to expect that the alteration of distance due to the rotation will not be equally insensible. We are not separated from our satellite by more than 240,000 miles, and as the diameter of the earth is nearly 8,000, the rotation may alter the distance of the moon from a station on the earth's surface by about $\frac{1}{30}$th of the whole distance, and the resulting change of the attracting force must be very considerable. An examination of the Greenwich magnetic observations, arranged according to lunar hours, has led Mr. Airy to the conclusion that no doubt can be entertained as to the existence of a luno-semidiurnal inequality, though he has failed to detect any luno-diurnal inequality. He also found, so close an agreement between the values of the luno-semidiurnal variation in the years of greater and also of smaller solar curves, that he suggests the two following "conjectural reasons for this remarkable association in the time-law of changes of solar and lunar effect. One is, that the moon's magnetic action is really produced by the sun's magnetic action; and a failure in the sun's magnetic power will make itself sensible, both in its direct effect on our magnets, and in its indirect effect through the intermediation of the moon's excited magnetism. The other is, that, assuming both actions, solar and lunar, to act on our magnets indirectly by exciting magnetic powers in the earth, which alone, or principally, are felt by the magnets, the earth itself may have gone through different stages of magnetic excitability, increasing or diminishing its competency to receive both the solar and lunar action." The ratio of the moon's disturbing action on the horizontal force is to that of the sun as 1 to 20.

We have just been considering the irregularities in the magnetic action of the sun and moon, which arise from the orbital motions of the earth and its satellite, and from the rotation of our globe, but there are still other variations depending on much more complex causes, that remain yet to be examined. A very important inequality has been detected in the daily range by several observers, and of late years by Mr. Chambers of the Colaba Observatory. It is a change that takes place in the amplitude of the range, not from season to season, but from year to year, and which completes its cycle in 10 or 11 years. Other periodical inequalities of the daily range have been more than suspected, as that of 22 years, noticed by Hansteen; and some of these may possibly be found to have a connection with such phenomena as the revolution of the moon's nodes. It will suffice to have mentioned these; but we must not so lightly pass over the decennial period, which is identical with the cycle of those great but irregular disturbances of which we must now say a few words.

The accurate study of magnetic storms was nearly impossible before photography was called to the aid of the observer; but now that every movement of the needle is faithfully recorded by the ever watchful light of the gas jet, a continuous curve shows at a glance the nature, extent, and duration of even the slightest disturbance. The arrangement of these self-recording magnets is extremely simple and equally effective. To each magnet, whose movements we desire to study, is attached a small mirror, and the rays from a gas jet falling on the mirror are sent by it to a cylinder covered with sensitized paper. A lens brings the rays to a focus on the cylinder, and this focus traces on the paper every movement of the magnet. A second mirror fixed immediately underneath the first, but having no connection with the magnet, sends the rays of the gas jet always in the same direction, and thus traces a base line from which the variations of the magnetic curve

can be measured with the greatest exactness. A clock turns the cylinder through a complete revolution in twenty-four hours, and the light being cut off for a few minutes every two hours, breaks are thus made in the curve, which serve as an excellent time scale. The magnetic curves, traced in this manner, are in general and lightly irregular lines, which reach their highest point towards 2 P.M., and are more or less curved at all hours of the day. Scarcely a day passes without some apparently accidental departure from the ordinary bend of the line, but these disturbances are often only of short duration. There are, however, occasions on which the magnets seem to be subject to the action of a disturbing force far exceeding in intensity any of those we have been hitherto considering, and subject itself to no apparent laws, but causing the needle not unfrequently to oscillate through several degrees of arc on either side of its mean position. It will be interesting to know what account can be given of this disturbing power, which assumes such Protean shapes, at one time raising a storm that dies away as gradually as it commenced, and at another bursting forth in an instant in all its fury; now continuing its disturbing action for days together, and then imparting but a single momentary impulse; affecting sometimes one element, and then another, and sometimes all together; and finally appearing not unfrequently at the same hour on several successive days.

The coincidence of these disturbances with the passing of earth currents, so perfectly recorded on the Greenwich curves; their never-failing appearance at all auroral displays; their simultaneous occurrence at places the most remote from each other; and, lastly, the agreement of their period of variation of intensity, as well as their maxima and minima with the decennial period, and the maxima and minima of sun-spot development,—all these facts will be most powerful aids towards the solution of our difficulty. Neither is it unreasonable to expect that some light may be thrown upon the question, if we examine with careful attention the not impossible connection of magnetic storms with solar outbursts, or with volcanic eruptions and violent earthquakes, with the variations of the wind, or even with the showers of falling meteors. Much of interest has already been ascertained in connection with these several points, but I will not tax too severely your indulgent patience by entering at present into these details.

I must, however, before concluding, allude for one moment to those researches of De La Rue, Stewart and Loewy, on solar physics, in which they have made a first step towards establishing a connection between the period of solar spots and the relative position of the planets. If this can be maintained; if the solar disturbances are in any way due to the combined action and reaction of the planets, and these again are found to be coincident with the great perturbations of terrestrial magnetism, shall we not be inclined to attribute a wider range to the magnetic force than is in general assigned to it? May not that, which has long been allowed to rank among the most extensively diffused of nature's agents, find a home in each individual member of the solar system, causing them to act and react upon each other as well by their magnetic energy as by their force of gravity? The perfect solution of such a problem would well repay many a year of persevering observation and of assiduous study, and well will those be rewarded by whose labors the general cause of terrestrial magnetism ceases to be one of the unsolved mysteries of cosmical physics.

RECENT NOTES ON THE METALLURGY OF IRON.

From the "Journal of the Iron and Steel Institute."

INTERNAL STRUCTURE OF IRON.

It has long been known that the arrangement of the particles in a mass of iron may be rendered visible to the eye by treating a smooth surface of the iron with any acid solution which etches or acts unequally on the different parts of it. Advantage has recently been taken of this property by Mr. Von Ruth, inspector of iron to the Dutch Government, as a means of recording or rather depicting on paper, the structure of any kind of wrought iron. He proceeds as follows: The sample of iron in question, such as, for example, the section of a rail having been brought to a uniform smooth surface, by planing or otherwise, is acted

upon by hydrochloric acid for from six to twenty-four hours, according to the nature of the iron, and the strength or temperature of the acid employed; so treated, the surface of the iron presents the appearance of an etched plate, the lines on which show the direction and arrangements of the fibres or grain of the iron. After this has been well washed with water to remove all superfluous acid, and dried, an engraving can be printed from it with printing ink in the usual manner; or it may be employed as a die, placing a sheet of ordinary carbon paper such as is used in manifold writing between it and the white sheet on which the impression is to be depicted. If a few sheets of writing paper are placed beneath this, to act as a pad, an ordinary letter copying press may be employed, when, upon removing the pressure, a good sharp picture is obtained on the white paper, which shows the details of the fibrous or granular structure of the iron in a very clear and distinct manner. The application of this simple and quick process as a means of studying the structure of iron in general, the formation of the pile in a rail, or the alteration of the fibre of the iron in the vicinity of a weld, is likely to be found of much service.

CRYSTALLIZED AND BURNT IRON.

It has often been observed that even the most fibrous iron, when long exposed to vibration or concussion, is liable to change the internal structure of its component particles, and become granular or crystalline, so as ultimately to snap or break off suddenly. This is very commonly found to be the case with the pump rods in mines, but it is probably less generally known that, in many instances, this change has been observed to be attended with a strong development of magnetism in the iron. A mine foreman in Germany declares that he always knew when a pump rod was about to break, when upon holding his iron miner's lamp near it, it was attracted and held up by the pump rod, as it was then, in his opinion, high time to replace it before it actually snapped.

In the Comptes-rendus des Sceances de l'Academie des Sciences, No. 10, for the 4th March, 1872, M. Caron brought forward a communication "On Crystallized or Burnt Iron," a subject which of late has also been written upon here in England with results which appear different from those obtained by M. Caron. After explaining that the name of "burnt" iron is applied to iron which (although previously of a good, strong, and fibrous quality) after having been suddenly heated to a white heat, and allowed to cool in the air without being hammered, is found to have become brittle, both when tested hot as well as cold, and to present a strongly developed crystalline fracture, he combats the generally received opinion that these alterations in the iron are produced by its having absorbed oxygen, declaring that this view is not supported by his chemical analyses, which have not shown any appreciable difference in the constituents of "burnt," as compared with good iron. Direct experiments were consequently made by M. Caron, as follows:—A bar of Franche-Comte iron, which was proved by all the ordinary tests to be of a good and fibrous quality, was cut into a number of pieces; some of these were heated suddenly to a white heat in a smith's forge; others were placed in porcelain tubes, and submitted to the action of currents of respectively hydrogen and nitrogen gases, when heated to as near as possible the same high temperature as those heated in a smith's forge. After having been allowed to cool under similar conditions, all these pieces, without exception, when broken across, showed the crystalline fracture of "burnt" iron, and, whether treated hot or cold, had apparently the same behavior; consequently as "burnt" iron can be produced at pleasure, in either oxidizing, neutral, or reducing atmospheres, it must be admitted, according to M. Caron, that this change cannot be dependent on the absorption of any gas in particular, but that it is simply due to the action which the heat has in altering the molecular arrangement of its particles. Again, M. Caron does not admit that iron becomes brittle, and liable to break after having been exposed to vibration, and declares that the idea that iron becomes crystalline, and more liable to fracture under the influence of cold in winter, is not tenable, and considers the following experiments as proving this not to be the case. Several pieces of the same bar of iron, before referred to, were exposed in the freezing works of M. Tellier, at Auteil, to temperatures varying from the freezing point of water down to about the zero of Fahrenheits thermometer, for more than four months; whilst others remained out in the air during last winter, when the frost was so severe that the thermometer even show-

ed as low as 4 deg. below zero (Fahrenheit). Attempts were made to break these bars, both when cold and when at a temperature of a few degrees above the freezing point of water, but in no instance were they found to have become brittle or crystalline, or to differ in strength from that of the original bar. M. Caron adds that all his experiments were made upon iron of undoubtedly good quality, and that he is not prepared to deny that it may not be otherwise with inferior iron, and that it is not improbable that iron of bad quality or workmanship may become perceptibly more brittle under the influence of low temperature. From the results of his experimental inquiry into the subject, he arrives at the conclusion that in all instances in which bars of iron break under impact, showing a crystalline fracture, it is certain that this crystalline structure pre-existed in the bar, and was generally due to bad workmanship, but never was brought about by the effects either of the actual strain or degree of cold to which the iron may have been exposed after having once been manufactured.

DIRECT REDUCTION OF IRON FROM THE ORE.

A patent has been obtained by Mr. T. S. Blair, of Pittsburgh, Pennsylvania, U. S., for reducing to the metallic condition, finely pulverized iron ores, by currents or jets of deoxidating gases, which at the same time propel the ore along the inclined bed of the furnace. The powdered ore is delivered from a sort of a hopper at the upper end of the sloping hearth of a heated chamber or furnace, into which oblique openings admit currents of gas being forced in.

SUPERHEATED BLAST.

The temperature of the air employed in smelting iron ores with charcoal, on the Continent, seldom exceeds from 600 to 700 deg. Fahrenheit. In Austria, however, recent accounts from the Steyrmarck district report that the employment of hot blast of about double this temperature (1,200 deg. Fahrenheit) has been attended with much superior results in the charcoal furnaces. In the manufacture of speigeleisen, a decided improvement in the smelting, especially as regards the amount of manganese reduced into the metal, is found to result from the use of an extremely hot blast.

PYROMETERS.

Mr. Robert Spencer, of New York, has recently patented making pyrometers with bulbs of iridium, enclosed in a casing or "brick," composed of a mixture of one part washed ganister, three of purified fire-clay, and one of pulverized calcined pots. No detailed description of the instruments themselves, or their working performance has, up to date, been received.

EMPLOYMENT OF QUICK LIME IN BLAST FURNACES.

In the Annales des Mines, Ser. vi., Vol. XX., pp. 525-546, M. Grüner, Professor of Metallurgy in the School of Mines at Paris, communicates a somewhat detailed paper on the use of quick-lime in blast furnaces, and on the employment of Hoffman's annular kiln for burning the limestone. It is well known that quick-lime has, since 1850, been employed, and is so at present, in many of the blast furnaces in England and Wales, as well as in Silesia and Belgium; but it does not appear to have met with that universal acceptance which it merits, principally for the reasons, according to Professor Grüner, that too little attention has hitherto been paid to the subject of its economical preparation, and to preventing the lime when once burnt from absorbing carbonic acid and water in the blast furnace itself, the first of which conditions is considered by the Professor to be obtained by the use of Hoffman's annular kiln, which he also recommends for the calcination of hydrated ores and carbonates of iron, as well as for burning fire-bricks; whilst the second, even if it is not possible to avoid altogether, can, he thinks, at least, be much diminished.

In a lime-kiln in which the carbon of the fuel is entirely converted into carbonic acid, it requires, according to Professor Grüner, a consumption of only 4.6 kilogrammes (10.14 lbs. avoirdupois) pure carbon to decompose or burn into quick-lime 100 kilogrammes (220.4 lbs.) limestone, whilst in a blast furnace, owing to the carbon being transformed only into carbonic oxide, it requires no less than 15.1 kilogrammes (33.29 lbs.) to produce the same effect, even without taking into consideration that the escaping gases from a blast furnace carry off in proportion more heat than from a lime-kiln; in addition to which, owing to the specific heat of the gases, the 44 kilogrammes (97 lbs.) carbonic acid in this quantity of limestone, will only require 0.36

kilogrammes (0.79 lbs.) carbon against 1.17 kilogrammes (2.57 lbs.) in the blast furnace. So that the decomposition of the carbonate of lime in 100 kilogrammes limestone, in conjunction with the heating up of the gases, will necessitate a consumption of 16.27 kilogrammes (35.86 lbs.) in the blast furnace, instead of only 4.96 kilogrammes (10.93 lbs.) in the lime-kiln; and when it it is remembered that some 600 kilogrammes (1,322 lbs.) of limestone are used as a flux, in coke blast furnaces, to every ton of pig iron produced, the difference will be as 29.76 kilogrammes (65.58 lbs.) per ton when the limestone is burnt outside the furnace, as compared to 97.62 kilogrammes (214. 16 lbs.) when it is charged into it in the raw state. Independent of this direct loss occasioned by using limestone, a further indirect increase in the consumption of fuel arises from the carbonic acid, which has been expelled from the limestone in the lower or hotter zone of the furnace, taking up carbon as it ascends to the top, thereby reducing itself to carbonic oxide at the expense of the fuel in the furnace, and, although Professor Grüner does not admit the correctness of Mr. Lowthian Bell's view that the entire quantity of carbonic acid in the flux is sent out of the furnace in the form of carbonic oxide, still, admitting that even as little as only one-quarter escapes in this condition, this would entail a still further consumption of 18 kilos. (39.67 lbs.) carbon to the ton of pig-iron produced, in addition to 22 kilos. (49.51 lbs.) for the absorption of heat, which must be restored to the blast furnace, or in all 40 kilos. (89.18 lbs.) per ton of iron, even when it is supposed that only one-fourth of the carbonic acid in the limestone has been reduced to carbonic oxide before passing off into the air; now, if this amount be added to the 97.62 kilos. (214.16 lbs.) previously obtained, we have a total of 147.62 kilos. (303.34 lbs.) of carbon consumed, when limestone is used, against only 29.76 kilos. (65.58 lbs.) required when quick-lime is substituted, or a clear gain of at least 107.86 kilos. (257.76 lbs.) pure carbon, or something like two and a half cwt. of coke per ton of pig-iron made, or about ten per cent. of the entire amount of the coke consumed in smelting the iron ore. In actual practice, Mr. Lowthian Bell only finds a saving of three quarters of a cwt. per ton of pig-iron, which would be about 3½ per cent., or but litle over a third of what has been estimated above, and this difference appears to be due in part to the imperfect burning of the lime, and more particularly to the presence of carbonic acid and watery vapor in the upper zone of the blast furnace; and, as a remedy, it is considered by Professor Grüner that the employment of dry calcined ore, dry coke, and fresh very strongly burnt lime, preferably somewhat aluminous or magnesian, will tend to bring the results of practice more approximating to those of theory.

For a description of the annular kiln of Hoffmann's construction, we must refer to the paper itself, but may mention that Professor Grüner states that one of these kilns, which in France cost at highest £1,000, is sufficient to supply the lime (25 tons per day) required as a flux for a blast furnace turning out 40 tons of pig-iron per day, and calculates that it would effect a saving of at least one franc per ton on the iron made, as the amount of inferior coal slack required would not exceed from 6 to 7 per cent. of the weight of the limestone burnt.

UTILIZATION OF BLAST FURNACE GASES.

A patent has been lately taken out by M. J. De Langlade for improvements on the utilization of the gases from blast furnaces employed in smelting iron ores; they consist principally in washing and purifying the gases first, and then sending them through a regenerative apparatus, the pressure of the gases being regulated by a special arrangement so as to enable them to be supplied at a constant and uniform rate for burning in reverberatory furnaces, or for other heating purposes.

UTILIZATION OF BLAST FURNACE SLAG.

In order to adapt the slag to such purposes as ballasting for railways, road metal, etc., the blast furnace slag at the George-Marie furnaces at Osnabruck, in Hanover, is allowed to flow from a height of 8 ft. into water, the effect of which is to convert it into large bean-shaped gravel; as fast as this is formed, it is lifted out of the water by an endless chain of buckets, which load it directly on to the railway trucks.

BESSEMER CONVERTERS.

Mr. Henry Chisholm, of Cleveland, Ohio, U. S., has patented improvements in steel converting vessels, amongst which may be mentioned, attaching the lower part of the

converter so that its surface or face along the top of the tuyeres forms a plane in line with the base and lining; also forming the joints of the sections of which the converter is composed, so that the lining shall be prevented from adhering to the bed of the vessel, when the sections require to be separated from one another, yet at the same time insure a close joint when they are put together.

BESSEMER STEEL FOR ARTILLERY.

Experiments are now being carried on at Neuberg, in Steyermarck, Austria, with a view to the employment of this class of steel for artillery purposes. When casting, the molten steel is, by means of hydraulic power, subjected to a pressure of 350 tons, the effect of which is to cause the air holes or pores in the external parts of the mass of steel to move towards and accumulate in the centre of the casting, where they do not affect the strength of the cannon, since they are eliminated in the act of boring out its calibre.

SILICON STEEL.

The process for making this description of steel, which was briefly noticed in the last quarterly report, has since been also patented in this country by its inventor, Charles Motier Nes, of New York; the pig-iron from which it is made is ordered to be melted in a suitable furnace, and when nearly melted, an addition of from 15 to 40 per cent. of its weight of silicious magnetic iron ore, mixed with coke, is made, and well stirred into the metal, after which it is run out into pots placed at the side of the furnace, holding about half a ton each, in which it is well stirred up with a rabble, previous to being tapped into the moulds. If wrought silicon steel is required, the same process is followed out, with only the difference, that when the steel is in the pots, it is stirred up until it "balls up," or comes to nature, as it is termed. Silicon steel, when of good quality, is stated to contain 0.600 per cent. carbon, along with 0.552 per cent. silicon.

CAST STEEL.

A patent has been taken out by Mr. H. C. Bosse, of Quebec, for treating pulverized iron ores, or metallic iron, in the form of fragments, clippings, or sponge, with an admixture of powdered graphite, anthracite, charcoal, coal, or coke, in definite proportions, in a Siemens regenerative, or other furnace heated by gas, so as to produce cast steel of any desired quality, at one operation. The materials must be free from all impurity, and in a state of fine powder; if melted in a furnace the charge may, if necessary, be covered with a flux of glass, or blast furnace slag, free from sulphur, or with slabs of soapstone, tiles, etc., but no covering is said to be required when gas furnaces are employed in which a neutral flame can be obtained. It is not very apparent where the novelty or improvement in this invention consists.

CRUCIBLES FOR CAST STEEL.

A peculiar variety of clay, to which the name of Wocheinite has been applied, from the place Wocheina, in Carinthia, Austria, at which it is found, promises to be a valuable material for the manufacture of crucibles, and other refractory ware, owing to its containing as much as 50.82 per cent. of alumina. Not being sufficiently plastic, it requires the addition of other clay, in order to enable its being easily moulded, and Dr. Schwarz reports that crucibles, made of this mineral, mixed with from one quarter to one half its weight of fire-clay, gave very good results.

MELTING STEEL IN LARGE QUANTITIES.

Instead of crucibles, Von Carnac employs for melting large quantities up to as much as a ton of steel at a time, a reverberatory furnace, with blast below the fire-grate; the body of the furnace itself is so long that the steel can be placed and heated at the end nearest the flue which leads to the chimney, before coming into the actual melting compartment; to the steel a quantity of broken glass or clean charcoal blast furnace slag is added, so as to form a flux or bath, standing about one or two inches thick above the molten steel; care must be taken that the glass employed has not been made with sulphate of soda, in order to prevent sulphur being given up to injure the quality of the steal.

SOLID CASTINGS.

The invention of Mr. J. B. Tarr, of Fairhaven, Massachusetts, U. S., is stated to be an arrangement by which a plunger driven upwards by a hydraulic press enters the mould containing the molten metal, and exerts a considerable pressure upon it; the principle appears to be the same as that

long employed by Whitworth, in Manchester, although the details differ considerably.

PUDDLING BY PETROLEUM.

According to the Pittsburgh commercial paper, and some French technical periodicals, petroleum is stated to have been successfully employed as fuel in puddling iron at the works of Laclede, of St. Louis, Missouri, U. S., for the last three months; the experiments are said to have been conducted by reliable and practical men, to have been made under varying conditions, and the iron produced tested in every way to prove its quality; the general results are stated to indicate that petroleum is the best fuel hitherto employed in puddling, both in respect to convenience, efficiency, and the superior quality of the iron produced. As no mention, however, is made of the expense attendant on its use, it is to be feared that on the score of economy, petroleum is not likely to recommend itself to the trade.

ROTARY PUDDLING FURNACES.

This system of mechanical puddling, which seems destined very shortly to replace all the present hand furnaces, has, owing no doubt to the higher rate of wages and the greater difficulty found in obtaining a full supply of skilled labor, attracted much more attention in the United States of America than has been accorded to it here in Great Britain. Full details of the Danks furnace, with its machinery and the results of its working in the United States, have already appeared in the Journal of the Institute, and since then, its introduction into this country has been attended with the most complete success. It remains, however, to mention, that within the last few months patents have been granted in the United States for two other arrangements for rotary puddling furnaces to, respectively, Mr. Willian Sellers, of Philadelphia, and Mr. William Baynton, a manager of a rolling mill at Pottsville, in Pennsylvania. As a description of both these inventions has already been published in the "Iron and Coal Trades Review," for April 24th, 1872, p. 327, which contains the specification of Mr. Baynton in full, we would refer to that journal for a more extended account of these inventions than the space still at disposal in the present report will allow.

ACTION OF CARBONIC ACID ON METALLIC IRON.

M. Tissandier, in the Compt. Rendus. lxxiv., p. 531, communicates experimental researches on this subject, showing, when carbonic acid gas comes in contact with metallic iron at a red heat, that the acid is decomposed, and protoxide ot iron is formed at the expense of one of the equivalents of oxygen in the gas, thereby reducing it to the state of carbonic oxide which escapes; this reaction is important in considering questions connected with the metallurgy of iron, and is proposed as a means for obtaining anhydrous protoxide of iron. The oxide thus prepared is black, brilliant, and crystalline, as well as magnetic; when heated to redness in contact with air it absorbs oxygen, and is converted into the red sesquioxide of iron.

MODERN EXAMPLES OF ROAD AND RAILWAY BRIDGES.*

By T. C. CLARKE, C. E.

Written for Van Nostrand's Magazine.

Books on engineering can be divided into two classes—the first class containing principles, with only enough examples to show their application to practice; and the second c ass containing examples only, leaving the reader to deduce the principles for himself. The value of books of the latter class consists in their fulness and in the accuracy and clearness with which all the details of the works illustrated are shown.

One of the best books of this kind that we have ever seen is that whose name heads this page. One of its merits is its capability of indefinite extension and its opportunity of growing better and better, the more numbers there are. We would suggest that its usefulness would be increased if there were greater uniformity in the statistical part of the descriptions of each bridge. This would prevent repetition and omission. In some of the bridges the very thing one wants to find has been omitted, while in others we find the same thing given in two places.

* Partially reprinted from "Engineering." London, 37 Bedford street, Strand. New York: sold by D. Van Nostrand. Six numbers published.

By arranging all the dimensions, weights, strains, etc., in a tabular form, the omissions become evident. It is understood that when engineers who have executed bridges will send drawings and descriptions of these works to the editors of "Engineering," they will (if the works are of sufficient novelty and interest to warrant it) publish them first in "Engineering," and afterwards, for convenience of reference, in this serial. We hope that the editors of "Engineering" will make it a condition hereafter of admission into their gallery that the authors send with each description a Table of Quantities, such as ends the description of Mr. Roebling's Suspension Bridge at Cincinnati, on page 165.

This book is valuable as showing how different men meet and overcome the same class of difficulties. It is an eminently suggestive book, and the hints that may be derived from it are of the highest value.

From the manner in which it is got up, although well printed on good paper and illustrated with excellent engravings, its cost is absurdly low, as compared with books containing a similar amount of information. Humber's larger work on Bridges, for example, the price of which is now quoted at $60, while the six parts of this book bound in one volume, can be obtained for $12; and yet this book is as full, as useful, and we think as ornamental as its more costly predecessor. For this merit, we hope the publishers will be encouraged to persevere and give us some more numbers.

Of the fifty-two structures illustrated in this book, nine are of American origin, and their designers have no reason to be ashamed of the appearance they make. Their details of construction are not so fully given as in those of English and Continental origin. This defect may, and it is hoped will be remedied in future numbers. Several of the greatest of American bridges are conspicuous from their absence, among which we may name Mr. Faile's bridge, at Louisville; Capt. Eads' bridge, at St. Louis, and Mr. Roebling's bridge at Brooklyn. We hope to see them hereafter.

This book will be a particularly valuable addition to the library of American engineers, because it contains the latest examples of bridges, which are pieces of architecture as well as of engineering. In this country, although we have many iron bridges, they are for the most part designed upon purely economical principles, for they chiefly carry railways over streams in wild and inaccessible places, where ornamental construction would be unseen. Moreover, we have so many bridges to build, and so little money to do it with, that capitalists frown upon all unnecessary expenditure, arguing justly that the prime object of investment is good dividends.

But another era is even now at hand. Engineers will soon be called upon to build city bridges, where architectural excellence is as important a requirement as structural merit. The bridge at St Louis is an example, and the new bridge at the Girard avenue entrance of Fairmount Park, in Philadelphia, another of this kind.

Therefore, it is that such books as this will become every day more and more sought for.

When engineers first began to use iron in place of stone in bridges, they naturally enough imitated stone arches, and for a long time arched construction was the only sort known. When girders with parallel top and bottom lines were first introduced, they looked so strange to eyes accustomed to curved lines, that critics condemned them as "hideous," "railway monstrosities," etc. Moreover, their architectural treatment was, to say the least, not happy. The principle of "survivals," which modifies and influences all of our attempts at ornament, both in dress as well as in architecture, here became manifest. Just as the first designers of English railway carriages thought it very necessary to paint the body of a stage-coach upon the side of the new vehicle which displaced it, so the first designers of parallel girders thought it highly architectural to paint or otherwise indicate an arch on the side of their straight girder. This may be be seen in Plate No. IV. of this book, illustrating the Penrith bridge, in Australia, where the engineer no doubt thought he had vastly improved the appearance of his bridge by this sham piece of constructed ornament.

To this day there are many persons who will not admit any possible beauty in a bridge which has not an arched soffit. To an eye, there is nothing grander in human construction than a massive stone arch. But when the proportions of stone are attempted to be imitated in iron, the effect is unsatisfactory even in a picture, and more so in reality. The light and graceful lines of a suspension bridge are always pleasing, and indicate the true treatment of iron con-

struction, which should gain its effect from a happy union of lightness and strength. The ornament should be suggested by and mark out the lines of construction, and not be applied like a masque, to disfigure and cancel the true meaning of the design.

The constructive lines of an open truss or skeleton girder bridge as modern engineering practice now constructs it, of wrought iron, are almost identical with those of a parapet or balustrade, as treated by mediæval architects, and which they made the vehicle of some of their happiest ornamental designs. Nay, more than this, the figure of a rectangle intersected by two diagonal lines, which is the foundation of one kind of open girder very commonly used, is often found in constructed ornament, such as is used for decorating a plain wall surface, deliberately chosen as the most ornamental figure or pattern.

To say, then, that a parallel girder cannot be made a beautiful piece of construction is merely a confession of ignorance. No Gothic architect would have the least trouble with it. The classic men whose ideas are all borrowed from Greece and Rome, can find no precedent nor example in their books for this new style, and hence they condemn it.

But we must return to our book. It is noticeable that while America leads the world in the boldness of her suspension and arched bridges, it is, strange to say, in conservative Holland that we must look for the largest span of girder bridge yet constructed, the Moerdych bridge of 493 ft. span, while the largest English span, the Britannia, is 460 ft., and the largest American, that at Cincinnati, is 420 ft.

Even in swing bridges, we have nothing that equals the span of the bridge at Brest, in France, of 383 ft. opening, or 191½ ft. from centre of turn-table to the outer end.

One of the boldest bridges illustrated in this book is the Clifton Suspension Bridge, built by the eminent Canadian engineer, Samuel Keefer, Esq. It is remarkable as showing how much can be done with a little money. It is narrow, being but 10 ft. wide, but its span is one of the largest yet constructed—1,264 ft. 4 in. between towers. The capital stock of the Company is reported at $400,000, but it is understood that the actual cost of the bridge is considerably less than this. The intention of its projectors is that it shall first pay for itself, and then show that a wider and stronger bridge will be a good and paying investment, and finally serve as the scaffolding upon which to erect its successor.

SPECIAL CHARACTERISTICS OF MEDIÆVAL GOTHIC ARCHITECTURE.*

From "The Architect."

In the various countries, and at the different times in which the art of architecture has been practised in its integrity, although its general character has been much the same, at the same period, wherever its votaries have held sway, it has always been modified in different localities according to the conditions under which the architects worked.

In our own country, as in Ancient Greece, where, for more than five centuries, architectural art was only understood in connection with certain traditional forms, and radical modifications were never made save with the general consent—pre-arranged or acquiesced in—of all the workers in the art, the peculiarities which are found in its decorative features in different countries may be traced with tolerable clearness to one or other of the following reasons, viz.:—Foreign influence, individual taste, or the nature of the materials obtainable.

In speaking of individual taste, however, the writer does not refer to those whims and fancies which are now generally spoken of as "matters of taste," for in ages when architectural forms were traditional, and architects no more thought of working in a foreign style than of placing their buildings upside down, their individual tastes, instead of being exercised in deciding on the style, had no wider scope than that of determining the outline and disposition of the various ornaments to be employed in their buildings, and in this they were to a great extent governed by the forms generally prevalent at the time, and by the character of the

* From a paper read before the Architectural Association British) by Mr. Frederick P. Johnson.

materials which nature had placed within their reach.

A careful study of the extent to which the Mediæval architects allowed their individual tastes to have scope in times when the differences between styles were unknown or disregarded, and of the manner in which they accommodated themselves to the exigencies of the localities in which they were placed in times when the difficulties attending the carriage of materials were such as to render this absolutely necessary, will prove of great value to the architect, now that all styles are made use of and all local restrictions removed. If, however, in pursuing this study he allow his prejudices to get the better of his right judgment, and attribute subtle and elaborate reasons for the most simple peculiarities, he will not only lose all the advantages to be derived from the study, but become little more than an archæologist.

The earliest form of the Mediæval Gothic work of this country which can in any sense be called architecture seems to be the Norman, and that only in their ecclesiastical edifices, their castles being merely the crude specimens of a still more crude system of engineering. A careful study, however, will show that the name of "Norman," as applied to the whole of the round arched style, must be accepted with considerable reservation, as many of its features, and those not the least essential, are scarcely to be met with in Normandy. It has generally been assumed, however, that every feature which is not absolutely Norman is due to a blending of the new style with that previously in use among the Saxons, and it has even been said that "were it worth while we might by this path arrive at some conclusions regarding Saxon architecture." Now it must be remembered that although the followers of William the Conqueror were principally Normans, there were in their ranks a great many adventurers from all parts of Europe, whose avarice had been sanctified and whose services enlisted by the benediction of the Pope, and that these, on their installation as nobles and church dignitaries of England, finding their churches in ruins or intending to build castles, generally brought masons with them from their native countries, so that when—although the general character of all buildings erected in England between the years 1066 and 1190 is decidedly Norman—there is found in many of them a great deal that, while absent, or at least rare in Normandy, is very largely to be met with in Burgundy, Lorraine, the valley of the Rhine, and even in the north of Italy, it seems more reasonable to attribute it to this cause than to any influence which could have been exercised on their conquerors by the Anglo-Saxons. It is possible, however, that some of the peculiarities of general arrangement noticeable in some of the earliest Anglo-Norman works may be due to this, although great care must be taken in attributing anything to an influence apparently so improbable.

Of the decorative peculiarities noticeable in the later portion of the Norman era, perhaps the most prominent is the strange aspect of the west doorway at Rochester, with many others in Kent, and one at Ely. The chevron ornament is not to be found in these doorways, the arch mouldings being ornamented with the signs of the zodiac and other heterogeneous designs, the spandrel filled with a *vesica piscis* grouped round with figures, and the lintel with a row of much smaller figures. At Rochester, two of the columns consist partly of statues, one male, and the other female. Now an almost exact counterpart of these doorways will be found at the west end of the cathedral at Autum, and, from fragments found at St. Benigne at Dijon, St. Ayoul at Provins, and the church at Avallon, it may be assumed that this mode of decoration was, at the commencement of the twelfth century, most common in Burgundy, and was therefore one of the importations brought thence by the missionary monks.

Another very prominent peculiarity of this period is that of carrying the arch-mouldings down the jambs, as exemplified at Iffley Church, near Oxford, and at a somewhat later date in the very rich doorways of Malmesbury Abbey Church. Of this there is but one instance in Normandy, viz., in the chancel of Than Church, near Caen, so that, although probably a Norman idea, it was not fully worked out save in England. At Worcester, in the nave transept, and chapter-house, the peculiarly Lombardic practice of working with two differently-colored stones is very prominent, and with regard to this it may be remarked that an Italian named Vacarius, whom Lanfranc (himself a Lombard) brought over for the purpose of encouraging the study of Italian law at Oxford, seems to have settled here, a copy of his works being still preserved in the chapter library.

In the nave of Hereford Cathedral, the great round columns of which seem to have been copied (in outline only) from Gloucester, and in the churches of Kilpeck and Shobdon in the neighborhood, the pure Norman mode of decoration is strangely combined with the interlaced forms and characters known as Runic, and most common in Ireland and the Isle of Man, the effect of which is in some instances extremely good.

In the North of England the plain circular pier was always more favored than the square, and the grouping of this with small shafts was commenced at an early date in the naves of Fountains and Kirkstall Abbeys, which, however, are in outline and arrangement Early English designs, although the form of the windows and the details, etc., are still Norman.

Now it may be noticed that all the abovementioned peculiarities are more or less referable to foreign influence, and when it is remembered that until the reign of King John (1199–1216), by which time the round-arched style had entirely died out, a great many of the English nobles were absentees, and that those who were not so, ruled with a rod of iron, it will be seen that as far as the encouragement of the arts was concerned, England was under a foreign influence far too strong to allow of the exercise of much individuality of style.

With regard to the influence of the nature of materials on the architecture of this period, it may be noticed that the absence of any kind of building stone, good or bad, in the counties to the north and east of London, gave rise to the practice of building with rubble, composed principally of old Roman bricks, in many instances without any casing whatever. The abundance of these bricks at the long-since evacuated colonies of St. Albans (Verulam) and Colchester (Camelodrum) must originally have suggested this mode of building, and the abbey at St. Albans and the priory at Colchester are probably the best specimens of it extant. In the latter it may be noticed that the use of the bricks forms part of the design, while in the former they are everywhere hidden with mortar.

The round towers of Norfolk and Suffolk are also attributed to the want of good stone for the quoins.

With the single exception of the cathedral at Kirkwall, in the Orkneys, Norman architecture does not seem to have penetrated into Scotland farther north than the Grampian mountains, and in the southern districts it is only to be known by its ornaments, as the round arch was retained in some instances even till the fourteenth century. It possesses, moreover, very little individuality of its own, the few larger works which are not of a Norwegian aspect bearing so strong a similarity to English designs that it would be difficult to doubt their common origin.

Almost all the excellences of Norman art, however, were merely the prototypes of the more beautiful works of succeeding ages, and the manner in which during the Transitional Period the good parts of the old style were modified and worked in with, and its barbarisms rejected from, the new, does more credit to the otherwise barbarous age in which it was done, than our works do to the far more enlightened and civilized period in which we live.

The abundance of good building-stone in the counties of Northamptonshire and Lincoln, with parts of those adjoining, must always have been an impulse towards the erection of large and elegant churches; and —of those erected in the thirteenth century —the fine arcaded towers of Stamford, West Walton, Felmarsham, and Whaplode, the lofty spires at Elton, Threckingham, Warmington, and Raunds, and the arcaded interiors at West Walton and Cherry Hinton, with other minor refinements too numerous to be mentioned, show that this impulse was not lost on the inhabitants of a district which was probably at that time one of the richest in England.

For the founding of a great architectural school in Yorkshire we are probably indebted to John de Eber, abbot of Fountains, who, on his induction to the abbacy in the year 1204, commenced the erection of the nave of his abbey. It should be noticed in the designs both of this and of Kirkstate Abbey, which was built at about the same time, that the main piers are grouped, although not with detached shafts, and that in all instances where greater length was required, the pointed arch is used, whereas in doors, windows, and wall arcades, although they are sometimes used indiscriminately, the round arch has the predominance. The mouldings, moreover, are more advanced in character, and the capitals, instead of showing any tendency towards being sculptured, are still scolloped.

As, in the erection of Byland, Jervaulx, and Hexham Abbeys, the style advanced, the grouping of the piers became more decided, the mouldings more deeply undercut, and the pointed arch more general, till, in the beautiful choirs of Rievaulx, Whitby, and Tynemouth, with the chapel of nine altars at Fountains, it may be said to be fully developed. The dog's-tooth ornament, the simplicity of which had, as with the chevron, secured its general adoption in this country, is the only enrichment to be found in them, and, in the abruptly introduced corbels which carry the responds of the eastern tower arch at Rievaulx, together with those at the ends of the transepts, the very strong predilection for moulded work is strikingly displayed. In some of the grandest of these buildings, moreover, such as the transept of York Cathedral and the choir at Whitby, wooden roofs formed the only covering, and the continuous arrangement of the clerestory, which caused the designer of the sham vaulting in the former of these examples so much inconvenience, is doubtless owing to this. The enclosing arches in the triforium at Whitby form a peculiarity apparently introduced from the south by the founder, Archbishop Gray, of Worcester, for the experiment, although it was tried in the westernmost bay of the choir at Rievaulx, was not followed out either there or elsewhere. The practice of introducing large rose windows in the spandrels of gables, as at York, Durham, and Beverley, may also be noticed, and these, with the large and fine lancet windows which carry them, give a bold aspect to most of these façades, which, while borne out in detail by the absence of sculptural decoration, forms the chief characteristic of the great school of architecture of which these for the most part dateless and unrecorded buildings are the monuments.

The first decidedly Gothic design in Scotland is the cathedral at St. Andrew's; from the somewhat incipient forms there prevalent we pass on to the abbeys at Jedburgh and Dryburgh, with several smaller ones, such as Cambuskennell and Kilwinning, and thence to the cathedrals at Glasgow and Dunblane, in which the Early Gothic style of Scotland reaches the climax of its excellence.

With the exception of some few individualities (mentioned by the essayist) Scotch ecclesiastical buildings of this date are merely reproductions of English designs, if not the actual work of English masons.

In Ireland, although the Early pointed style gained a somewhat better footing than that of the Normans had, the few specimens that remain are very rude—the piers are square and the arches have flat soffits, while the remaining details are of an equally barbarous character. The churches at Dublin and in the surrounding counties, which formed what was called the "English pale," can scarcely be regarded as specimens of Irish Gothic art.

The separate existence of these different schools of architecture, however, gradually decreased in proportion to the increasing facilities of intercommunication, and the general adoption of tracery in all of them, at about the year 1260 or 1270, was the first decided step towards the unification of style all over the country.

The influence of the want of building stone in the county of Essex already noticed, also led to the extensive use of wood as a building material, and to the early part of the fourteenth century the first examples worthy of mention may be referred. Church porches are the most important of these works, and many of these, such as those at Aldham and Bramwell, are of very good design. The wooden spires which are so common in Surrey and Sussex are also, probably, due to this influence.

The want of good building stone probably necessitated the construction in wood of the lantern surmounting the "octagon," as it is called, at Ely (1328—42), and the impulse which this deficiency gave towards the study of the application of woodwork was already beginning to display itself in many beautiful roofs and screens, which even now exist in the churches of Norfolk and the Fen country.

In the cathedral gateway at Norwich, and the beautiful priory church at Walsingham, in Norfolk, another way of meeting the exigency displays itself in the use of cut flints; and the carefulness with which they are fitted into the stonework, and the surface decoration worked out by these means, has a very fine effect.

With the general adoption of Perpendicular forms, which, introduced at Gloucester about A.D. 1340, had, on the opening of the fifteenth century, overspread the whole kingdom, almost all the individuality of the hitherto self-existent schools of architecture in this island is lost.

Apart from a few and, comparatively speaking, unimportant peculiarities, the Perpendicular style is the same all over the kingdom, and this fact, combined with that of its being peculiar to this country, renders it, of all English Gothic style, the only one that can consistently be called a national style.

In conclusion, the author said he had attempted to show that all the individualities of Gothic architecture existing in different parts of England were to be traced to foreign influence, individual taste, or the nature of the building materials obtainable, although the more important peculiarities were probably due to the exigencies arising from the last-mentioned cause; and, however important those arising from foreign influence or individual taste might have been, they were always subservient to the necessities imposed by these exigencies, and in most cases to the predominance of the forms generally prevalent at the time.

TRACTION ENGINES OR ROAD LOCOMOTIVES.*

By Prof. R. H. THURSTON.

THE PAST, THE PRESENT, AND THE FUTURE OF STEAM ON THE COMMON ROAD.

When, during the last century, the steam engine had so far been perfected that the possibility of its application to other purposes than the elevation of water had become generally recognized, the problem of its adaptation to the propulsion of carriages was attacked by many engineers and inventors.

As early as 1759, Dr. Robison, who was at the time a graduate of the University of Glasgow, and an applicant for an Assistant Professorship there, and who had made the acquaintance of the instrument maker, James Watts, when visiting the workshop, called the attention of the latter, who was probably then more ignorant of the principles of the steam engine than was the young student, to the possibility of constructing a carriage to be driven by a steam engine, thus, perhaps, setting in operation that train of thoughtful experiment which finally earned for Watt his splendid fame.

In 1765, that singular genius, Dr. Erasmus Darwin, whose celebrity was acquired by speculations in poetry and philosphy as well as in medicine, urged Matthew Boulton, subsequently Watt's partner, and just then corresponding with our own Franklin in relation to the use of steam power, to construct a steam carriage or "fiery chariot," as he poetically styled it, and of which he sketched a set of plans.

A young man, named Edgeworth, became interested in the scheme, and, in 1768, published a paper which had secured for him a gold medal from the Society of Arts. In this paper he proposed railroads on which the carriages were to be drawn by horses, *or by ropes from steam-winding engines.*

These were merely promising schemes, however. The first actual experiment was made, as is supposed, by a French army officer, Nicholas Joseph Cugnot, who, in 1769, built a steam carriage which was set at work in presence of the French Minister of War, the Duke de Choiseul. The funds required by him were furnished by the Compte de Saxe. Encouraged by the partial success of the first locomotive, Cugnot, in 1770, constructed a second, which is still preserved in the "Conservatoire des Arts et Metiers," Paris.

Watt patented a road engine in 1784, after he had made the more essential improvements in general design and in the details of his pumping engine. At about the same time, Murdoch, his efficient lieutenant, completed and made a trial of a model locomotive, driven by a "grasshopper engine," having a steam cylinder $\frac{3}{4}$ in. in diameter and 2 in. stroke of piston. It is reported to have run 6 to 8 miles an hour, its little driving wheels making from 200 to 275 revolutions per minute.

In 1786, Oliver Evans asked of the Pennsylvania Legislature the monopoly of his method of applying the steam engine in driving flour mills *and to propelling wagons.* In the same or following year, Wm. Symington constructed a working model of a steam carriage which may still be seen in the Patent Museum, at South Kensington, London.

* Read before the Polytechnic Club of the American Institute. The above is an abstract of the report as given in the "Journal of the Franklin Institute."

In 1802, Trevithick and Vivian took out a British patent for a locomotive engine, and their model is also preserved in the Museum of the British Patent Office.

In 1804, Oliver Evans completed a flat-bottomed boat to be used at the Philadelphia docks, and, mounting it on wheels, drove it by its own steam engine to the river bank. Launching the craft, he propelled it down the river, using its steam engine to drive its paddle wheels. Evans' "Oructor Amphibolis," as he named the odd machine, was the first road locomotive that we find described after Cugnot's time.

Evans assured incredulous legislators that carriages propelled by steam would soon be in common use, and offered a wager of $300 that he could build a "steam wagon" that should excel in speed the swiftest horse that could be matched against it.

In 1821, Julius Griffiths of Middlesex, England, made a steam carriage for common roads, which he designed to carry passengers, and which was probably the first ever constructed for that purpose only.

During the succeeding ten or fifteen years, Messrs. Burstall & Hill, of London and Edinburgh, Mr. Goldsworthy Gurney, the Messrs. Seaward, W. H. James, Walter Hancock, Ogle & Summers, Sir Charles Dance, and others in Great Britain, and Harrison Dyer, Joseph Dixon, Rufus Porter and a Mr. James, in the United States, with, probably, many others whose names are unknown in history, attacked this important and seductive problem with varying success.

In December, 1833, about 20 steam carriages and traction road engines were running, or were in course of construction, in and near London.

In our own country, the roughness of roads discouraged inventors, and, in Great Britain even, the successful introduction of road locomotives, which seemed at one time almost an accomplished fact, finally met with so many obstacles that even Hancock, the most ingenious, persistent and successful constructor, gave up in despair. Hostile legislation procured by opposing interests, and, possibly also, the rapid progress of steam locomotion on railroads, caused this result.

In consequence of this interruption of experiment, almost nothing was done during the succeeding quarter of a century, and it is only within a few years that anything like a business success has been founded upon the construction of road locomotives, although the scheme seems to have been at no time entirely given up.

J. Scott Russell, Boydell, and a few others in England, and Messrs. Roper, Dudgeon, Fawkes, Latta, and J. K. Fisher, in the United States, have all, at various times, labored in this direction.

The last-named engineer designed his first steam carriage in 1840, and is still at work.

Abroad, a few firms have succeeded, within a few years past, in making a business of considerable extent in constructing road locomotives for hauling heavy loads, and in building steam road rollers.

While steam carriages of high speed, and adapted to the transportation of passengers, have not yet been successfully introduced, a most promising start has been made in the application of steam to the heavier kinds of work on the common road.

The great impediments seem to be the roughness and bad construction of the ordinary highway, the dangers arising from the taking fright of horses, the engineering difficulties of construction, and the limited power of the machine as it has usually been built. Hostile legislation might perhaps be placed in the category, but we are probably sufficiently far advanced in civilization today to be able to secure liberal legislation when the people shall be satisfied that the introduction of the road locomotive will be of great public advantage.

The capabilities of the road locomotive are readily determined by experiment, and the following paper embodies the results of several series of trials.

When in Great Britain, some two years ago, the writer found that the construction of traction engines and steam road rollers was occupying the attention, to a considerable degree, of several engineering firms, among whom may be mentioned Messrs. Aveling & Porter, Tuxford & Sons, Burrell, Ransomes Sims & Head and others, Messrs. Fowler & Co. were constructing machines to be used in steam ploughing, an application of steam to which they were giving especial attention.

The first-named firm seemed a leading one in the business of building road locomotives, and about 400 workmen were kept employed by them. Their engines seemed well built and had an excellent reputation, but, unfortunately, the short time available merely permitted an inspection of their ma-

chines, and no opportunity offered to witness a pre-arranged trial, or even to see them at ordinary work.

More than two years previous to the period just referred to, a trial of these machines was made by the well-known French engineer, Mon. H. Tresca, *Sous-directeur du Conservatoire Imperial des Arts et Metiers*, Paris, and in presence of the equally distinguished English Professor, Fleemin Jenkin. The report was submitted to the *Directeur*, General Morin, January 15th, 1868.

The results may be summarized as follows :

1. The co-efficient of traction was determined to be about 0.25 on a good road with easy grades.

2. The consumption of coal was found to be 4.4 lbs. per horse-power per hour.

3. The consumption of water was determined to be 132.2 gallons an hour with the "10-horse" engine.

4. The "co-efficient of adherence," or of friction between the wheels and the soil, was 0.3.

5. A rate of motion of 7 miles an hour produced no special difficulty in managing either the locomotive or its load.

At about this same time, M. Servel, *Ingenieur en chef de la Compagnie Générale des Messageries à Vapeur*, conducted a series of experiments with a similar machine upon paved and upon macadamized roads, during what he describes as the most trying of winter weather. Under such unfavorable conditions, M. Servel reports the following distribution of weights by *per centum :*

Weight of locomotives.....	41.4
" wagons.....	18.2
" paying load.....	40.4
	100.

The average total weight of three loaded wagons, which was the usual load, was 22,575 kilogrammes, or very nearly 22 tons.

The experiment was made in 1867–68 of applying these engines to the towage of boats on the French canals. The results seem to have been very encouraging. M. Geraldi reported that an 8-horse engine towed on the canal between Caen and Oyestreham, a fleet, having an aggregate measure of 800 tons, at the rate of three miles an hour, and that the speed had been pushed, on occasion, up to six miles an hour. The latter speed was not considered an advisable one, however.

M. Carfort reported to M. Huet that a 6-horse engine, doing similar work on the Dunkerque and Saint Omer canal, had towed 800, tons, and was regularly towing 500 to 700 tons at an expense not exceeding 40 per centum of the cost of horse power.

In the year 1871 a number of traction engines were exhibited before the Royal Agricultural Society of England at their show at Wolverhampton, and the judges appointed by the Society made a series of exceedingly interesting and instructive tests.

The authorities already quoted furnish valuable information as to the capabilities of this system ; but the writer, in common with many others of the profession, has long been desirous of learning more of its value on good roads by personal observation. Fully believing in the ultimate and general adoption of steam traction on our streets and roads, it yet seemed a question whether there might not exist some unanticipated obstruction, or some serious difficulty not referred to in published reports.

The desired opportunity recently presented itself when the writer was requested to conduct a public trial of the road locomotives of Messrs. Aveling & Porter, and of their steam road rollers, and was proffered every desired facility for making a thorough examination of the construction of the machines, and for testing their powers of traction and manœuvring. Mr. W. C. Oastler, agent for the builders, promised to furnish one locomotive, and Mr. Daniel Brennan, Jr., President of the Telford Pavement Co., of Orange, N. J., offered a road locomotive and a steam roller, with the privilege of taking as a trial ground any portion of the macadamized road which the Company were constructing at South Orange.

Engagements permitting, a day, Saturday, September 21st, was taken for a visit to Orange to inspect the engines, and to select a trial ground. The trial was to take place October 1st, and invitations were extended to and accepted by the Commissioners of Public Roads for Essex and for other Counties of New Jersey, and by many well-known engineers of New York and vicinity.

Two road steamers or traction engines and a steam road roller were brought out for exhibition and trial.

No. 1 was a new road locomotive built by Messrs. Aveling & Porter; it had previously done no real work.

The following are the principal dimensions :—

Weight of engine, complete, 5 tons 4 cwt.	11,648 lbs.
Steam cylinder—diameter in inches.	7¼.
Stroke of piston—inches	10.
Revolution of crank to one of driving-wheels.	17.
Driving-wheels—diameter in inches....	60.
" —breadth of tire in inches....	10.
" —weight, pounds each.....	450.
Boiler—length over all, feet.	8.
" —diameter of shell, inches.....	30.
" —thickness of shell, inches .....7–16.	
" —firebox sheets, outside thickness in in.	¼.
Load on driving-wheels, 4 tons 10 cwt. = lbs. 10,080.	

The boiler was of the ordinary locomotive type, and the engine was mounted upon it, as is usual with portable engines.

The driving wheels were of wrought iron, strong but light in their construction, and were fitted with strips of iron, thickest at the middle of their lengths, which were laid diagonally across the face of the wheels, with separating spaces of about 2 in. between them. The angle was such that one end of one strip would come to a bearing on the ground just as the opposite end of the preceding strip was leaving it.

The builders claim that this method of obtaining tractive power in the wheel gives the engine a pulling power, on good ground, equal to 0.45 of the insistent weight,* while, with the smooth wheel used in the trial described in the report to the Royal Agricultural Society, quoted above, that coefficient is but 0.25.

On extremely hard and smooth roads, bolts may be inserted in the wheel rim, whose heads give better holding power than even these iron strips, and on very soft ground the same bolts are used to secure to the rim of the wheel pieces of angle iron, called by the builders "paddles," which take a good hold upon the more unstable kinds of soil.

The weight of this locomotive rested principally upon the driving wheels; about 15 per centum was left upon the forward axle to insure good steering power.

The total weight on the drivers was somewhat increased when pulling a load, usually, by the inclination of the line of traction downward from the pulling bolt to the point of attachment to the load.

The forward axle is fitted with wheels of 42 in. diameter and 8 in. face; it swings about a king-bolt which is secured above in a bracket secured to the under side of the boiler smoke-box, and is steadied by a strong rod, connecting its lower end with the forward end of the fire-box.

Chains were led from each end of the axle to a shaft carried on the forward end of the fire-box, around which they wound in such a manner that turning this shaft would swing the axle.

A hand-steering wheel, conveniently arranged near the throttle and reversing handles, turned this shaft, being connected with it by means of a worm shaft and pinion.

A tank at the rear of the locomotive carried coal and water in its compartments, and afforded a standing place for the engine-driver, from which he could readily reach the various handles and gauges.

Draught was secured by means of the exhaust, and, when desired, the latter could be turned into the water tank, thereby securing a double advantage, heating the feed water and rendering the engine noiseless.

The boiler and steam cylinder were both well protected against losses of heat by coverings of felt and lagging.

No springs were used on the engines exhibited, as, being intended for heavy work at slow velocities, their advantages would not, it was supposed by the builders, justify the expense and complication attending their use.

A strap brake was fitted on the driving axle for the purpose of controlling the engine on heavy grades.

Road locomotive No. 2 was of the same size and of similar make to No. 1. It had been two years in use, or longer, on the roads made by the Telford Pavement Company, as a steam road-roller. To convert it into a road-roller, its ordinary driving-wheels had been removed, and in their place, were fitted a pair of cast-iron wheels, of similar diameter, but of 20 in. breadth of face, and weighing 3,800 lbs. each. Their faces were left smooth, as hauling power was not desired, and as it was intended that they should leave the surface of the road as smooth and as firmly compact

* This is equal to that obtained with the india-rubber tired wheel at Wolverhampton. A committee of the Royal (British) Engineers, consisting of Colonels Gallway, Wray and Lennox and Captain Home, compared the pulling power of these wheels with that of india-rubber tired wheels in November, 1870, using the same engine with both, on Star Hill, near Rochester. They found them to be equal, with equal insistent weights.

The writer regrets that he has no personal experience with which to compare these results.

ed as possible. In these driving wheels, the engine carried an excess of weight of 6,700 lbs. as compared with No. 1. In statements of work done, this excess should be entered as a part of the paying load where No. 2 is employed as a traction engine. The great weight of these wheels has an important effect in preventing the liability of slipping, which is a consequence of their smooth surface, and should bring up the equivalent coefficient of adherence, in terms of the original weight of the engine, to about 0.42, or nearly equal to that of No. 1 with its regular traction wheels. As, during the trials about to be described, no slip was in any case observable, this difference would not in any way affect the results.

The weight of the steam road-roller offered for trial, everything included, was 15 tons, or 33,600 lbs.

The engine and boiler were of the same general dimensions as the road locomotives already described. The furnace door was placed at one side of the fire-box, and the reversing lever, throttle handle, and steam gauge were all brought to the same side, the engine driver standing on the frame of the machine, which is sufficiently broad and is immensely strong. The tanks for fuel and water were so placed as to be within reach of the driver. The steering apparatus was located at the side opposite the working gear of the engine, and was operated by the engine driver's assistant, who finds standing room on that side. The whole machine was carried on four large wheels, with broad thread, covering a total width of 6 ft. Its weight exerts a compressive force of 5,600 lbs. on each foot of width, or 467 lbs. on each inch.

The wheels had holes drilled in their faces, like the wheels of the traction engines, in which could be inserted strong spikes for breaking up old roads previous to making repairs, or for loosening the surface previous to metalling new roads.

The preliminary examination of the proposed trial ground and its selection took place late in September, and a half day was devoted to an examination of the engines and of the road-bed. Engine No. 1 was found at Orange, and, after a careful examination had been made of its design and construction, the driver started with it over an awkwardly narrow and winding piece of road, traversing it without apparent difficulty, and going forward and backward at varying speeds, steering with evident ease and accuracy.

The writer then took the place of the driver, and, although the experience was a novel one, found no difficulty in acquiring, in a very short time, such command of the machine that it became evident that but little training would be required to enable any ordinary intelligent mechanic to manœuvre the locomotive on the most difficult road. The reversing handle, the throttle and the steering wheel were conveniently located and easily operated. Reversing could be performed promptly, notwithstanding the weight and consequent momentum of the fly-wheel, which, it had been apprehended, might cause loss of time, if not an excessive strain, when reversing suddenly. Steerage seemed almost equally easy and precise, whether going forward or backward. A block of wood 6 or 8 in. high, thrown under one forward wheel, was driven over without apparent difficulty or injury to the machine.

After these experiments and the examination of the locomotive were concluded, the party rode over to South Orange, where a portion of road containing heavy grades was selected for the public trial of the locomotives which had been described. It consisted of a short section of nearly level road, in the village of South Orange, near the railroad station, and of that part of the road, on either side of this nearly level stretch, which ascends from the valley by a moderately heavy grade, on the eastern side, and by a very remarkably steep grade on the western side. The road-bed was remarkably smooth, hard and compact.

FIRST TRIAL.

The first trial was made at 10 o'clock, A. M., Oct. 1st, with Engine No. 1.

The load consisted of two wagons heavily laden with stone, and weighing, with their loads, 5,000 and 5,600 lbs. respectively, a total of 10,600 lbs.

This load was drawn up a grade of 10.10 in 100—equal to 533.28 ft. per mile.

The wagon tires were very narrow and much worn, and were observed to cut into the roads somewhat, notwithstanding the thoroughness with which the road-roller had done its work.

The driver of the engine was a lad without experience. By putting coal in large pieces on his fire, at the worst portion of his route, he caused his steam pressure to fall

rapidly, and was compelled to stop on the heavy grade until the pressure rose to 90 lbs. again, when another start was made, and the top of the hill was reached without apparent difficulty.

Some annoyance was experienced from priming, partly in consequence of the low pressure maintained in the boiler, but principally, no doubt, because the boiler had not been in use long enough to thoroughly clean its interior surfaces. This engine was, therefore, detached, and No. 2, which had been long in use, was taken for the next trial over this same course.

SECOND TRIAL.

A trial was next made of the power of manœuvring possessed by these engines.

No. 1 was stationed at a part of the road which had not been rebuilt, and where the ground was soft and uneven. The machine turned *continuously* for a considerable time, in a circle of 18 ft. radius, crossing the gutter at one part of the course, and gave no evidence of difficulty arising from any cause. The engine could turn, when required, in a space slightly greater than its own length, by carefully backing and filling.

THIRD TRIAL.

Locomotive No. 2, being attached to the same two wagons used in the first trial, drew them up the hill to the summit without halting, and without priming or difficulty of any kind. The steam gauge indicated, at starting, 120 lbs., and at stopping, 90 lbs. pressure of steam.

The time occupied in traversing 1,450 ft. was 3½ min.; the speed being about 4¾ miles per hour. Returning to the foot of the hill, a third wagon was brought up and attached, with the other two, to the same locomotive.

FOURTH TRIAL.

The total load in wagons was now 16,530 lbs., and the excess in weight of the rolling wheels of this engine over the regular and, as already stated, more efficient traction driving-wheels of No. 1, brought up the figure to a total of 23,230 lbs.

This load was taken up the same heavy grade in 4 min.—almost precisely 4 miles an hour. The steam pressure varied from 105 to 120 lbs.

The action of the driving-wheels was carefully observed, but no evidence of slip was discovered, with even this heavy load.

The proprietor and agent both desired to try again, using the same engine, with a fourth wagon added to the train; but time was passing rapidly, and it was decided to change the ground, and to experiment with heavier loads on less exceptional grades.

FIFTH TRIAL.

The locomotives and wagons were taken across the railroad track to the other portion of the selected road, where the grade was 4.27 ft. rise in 100 of horizontal distance, or 225.46 ft. per mile. This did not approach, in steepness, that already described, but it was, nevertheless, a heavy grade.

Engine No. 1 was here attached to a train of six loaded wagons, weighing, all together, 340,080 lbs. Starting with 95 lbs. of steam, it drew the train steadily, and with apparent ease, except when, as in the first trial, priming occasionally produced some annoyance.

SIXTH TRIAL.

The train was stopped, engine No. 2 was substituted for No. 1, and, with the same load, on the same grade, a trial of speed was made. The mean speed, over the whole course, was 3.6 miles per hour, that figure being somewhat exceeded at times. The steam pressure varied between 90 and 105 lbs. The length of the course was 1,435 ft.

SEVENTH AND LAST TRIAL.

A train of 10 wagons was next made up, and engine No. 2 was attached. The total load was now 63,400 lbs.; the course was the same as during the preceding trial. Several unsuccessful attempts were made to start this load, the connecting chains snapping as soon as the strain came fully upon them. Chains were finally obtained of sufficient strength, and a start was made. The load, increased by the weight of a large number of men and boys who clustered upon the wagons, was taken to the top of the hill without accident and without a halt. The steam pressure varied between 85 and 124 lbs per sq. in. At the lower pressure, the throttle was carried full open, and it was evident that all the steam that the engine would take was required to keep the piston moving. At starting, the engine exhibited a tendency to rise forward. It may be concluded from these two facts that this load was about a maximum for the en-

gine when carrying 85 lbs. of steam, and that, while drawing it, nearly all the weight of the engine was brought upon the drivers.

Even during this trial no slip of the driving-wheels could be detected, notwithstanding the fact, already stated, that they were smooth on their wearing surfaces. The marks left, by the bolt holes in their rims, upon the surface of the road were perfectly distinct and undistorted. The engine gave no trouble by priming.

It was noted, during the trials on this grade, that the wagons would just start backward down the hill when detached, and it is therefore to be concluded that the coefficient of traction on a level, corresponding with the coefficient of rolling resistance, must have been very nearly represented by the tangent of the angle of the grade, or about 0.0427; it may be assumed at 0.04.

Coal.—The amount of coal used on this engine during the day was 350 lbs.

Effect on the Road-bed.—During all trials, the effect produced by the locomotive upon the road surface was carefully observed and compared with that produced by the hoofs of the horses, which were at intervals climbing the second grade with loaded wagons similar to those used with the traction engine. The hoofs of the horses, it was noticed, cut into the road somewhat, loosening the metalling and injuring the surface, thus increasing the resistance offered to the vehicles following them. The wheels of the traction engine, on the contrary, very perceptibly compacted and improved the road, and thus, to some extent, reduced tractional resistances. There was a marked difference in the action of the two motors upon the surface, and it was evidently a matter of economical importance.

Horses vs. *Steam.*—Each wagon could usually be drawn to the top of the hill by two good horses, but only with very great effort. Three were required to do the work as comfortably as it should be done, and this number could pull a single load steadily and with moderate exertion.

The locomotive on this grade therefore performed the work of between twenty and thirty horses. We may conclude that it can, with 85 lbs. of steam, draw a load which would require the severest exertion of twenty horses. The maximum steam pressure proposed by the builders of these engines is 130 lbs., at which pressure they are still far below the limit allowed by our own laws.

It was now late in the afternoon, and it was concluded to suspend work for lack of time to make up other trains.

The great steam road-roller was brought forward; its construction was examined by all present, and its effective action in compacting the road was observed. It moved backward and forward, on this grade of 225 ft. to the mile, rapidly and steadily, and was said by its owner to be able to ascend the grade of 533 ft. to the mile, upon which the first trial was made with the traction engine.

The day's work thus terminated and the party separated. The information which had been acquired respecting steam traction and the construction of metalled roads was most valuable, and it was considered by all that the day had been spent pleasantly and profitably.

RÉSUMÉ.

Reviewing the experiments on the Aveling & Porter road locomotives and steam road-roller, we may make a brief *résumé* of the facts developed, thus:

1. A traction engine may be so constructed as to be capable of being easily and rapidly manœuvred on the common road and in the midst of any ordinary obstructions.

2. Such an engine may be placed in the hands of the average mechanic, or even of an intelligent youth of 16*, with confidence that he will quickly acquire, under instruction, the requisite knowledge and skill in its preservation and management.

3. An engine weighing rather more than 5 tons may be turned continuously in a circle of 18 ft. radius without difficulty and without slipping either driving-wheel, even on rough ground, and may be turned in a roadway of a width but slightly greater than the length of the locomotive, by proper manœuvring.

4. A road locomotive, weighing 5 tons 4 cwt., has been constructed, which is capable of drawing, on a good road, more than 23,000 lbs. up the almost unexampled grade of 533 ft. to the mile at the rate of four miles an hour.

5. Such a locomotive may be made, under similar conditions, to draw a load of more

* The manufacturers state that one of their most skilful drivers, at Wolverhampton, was a boy of 14.

than 63,000 lbs. up a hill rising 225 ft. to the mile, at the rate of two miles per hour, doing the work of more than twenty horses.

6. The action of the traction engine upon the road is beneficial, even when exerting its maximum power, while, with horses, the injury to the road-bed is very noticeable.

7. The coefficient of traction is, with such heavily laden and roughly made wagons as were used at South Orange, and under the circumstances noted, not far from *four per centum* on a well made macadamized road.

8. The amount of fuel, of good quality, used may be rekoned at less than 500 lbs. per day, where the engine is a considerable portion of the time heavily loaded, and, during the remaining time, running light. It may be considered, without probability of serious error, that, during the trials at South Orange, Engine No. 2 performed pretty nearly an average day's work.

DEDUCTIONS.

A number of interesting problems may be solved by reference to the facts learned here. A comparison of the efficiency of the road steam traction engine with that of horse-power, in drawing heavy loads, is especially important, and we will now make such a comparison, basing it upon the most reliable data at hand.

Traction Force.—It has been already stated that Engine No. 2 developed a tractive force equal to that of twenty horses.

The actual tractive force may be determined as follows:—The coefficient of traction was, as has been shown, not far from 0.0427, which is also very nearly the maximum figure given by General Morin, as determined by his experiments with "dray-carts" and "*chariot-porte-corps d'artillerie,*" upon metalled roads and upon roads paved with sandstone.* This coefficient is large, partly in consequence of the very slight breadth of the wheel tires and the small diameter of the wheels of the wagons used, and partly because the wagon bodies were not mounted on springs. To be absolutely certain that no error is committed by over-estimation in the following calculation, this coefficient will be taken at 0.03.

The actual tractive force required to overcome the rolling resistance was, then, $63,400 \times 0.03 = 1,902$ lbs. The force required to overcome that component of the force of gravity which directly resisted the motion of the load, in this case where the road lay at an angle with the horizontal, whose tangent was 0.0427, was W Sin $\theta = 2,700$ lbs.; the total resistance was therefore 4,602 lbs.

Including the weight of the traction engine itself, these figures become 2,251 and 3,002 lbs., giving a total of 5,253 lbs. direct resistance, and a coefficient of adherence of $5,253 \div 18,348 = 0.28$, which slightly exceeds that found on earlier trials of smooth wheels.

Experiments made by Capt. Robt. Merry, at the Jackson Iron Mine, Negaunee, Mich., and the observations and experiments of the writer, indicate the maximum direct tractive force of a good horse to be about 250 lbs. This corroborates the estimate already made, making *the tractive power of this engine equal to that of twenty horses.*

Deducing from the above the weight which could be drawn, on an equally excellent but level road, by this locomotive, the coefficient of traction being the same, we find it equal to $\frac{5.253}{0.03} = 175,100$ lbs., or very nearly eighty gross tons, and, excluding the weight of the locomotive (163,452), 75 tons. With the machine, as with the animal, it would not be expected that, in regular work, on ordinary roads, more than one-half of the maximum power would be exacted,* although, with such a reserve, the machine possesses a decided advantage over the animal.

Working Time.—The working time of a horse is usually considered to be eight hours per day for dray horses, and less for carriage horses. The dray horse which is kept in harness eight hours per day, is usually standing unworked a considerable proportion of this time while his load is handled, and also during one-half, usually, of the remaining time, his vehicle is drawn unloaded. The horses of the Third Avenue street railroad, in New York city, are worked less than six hours per day, and are given one day in seven as a day of rest. This is about equal to the working time of horses and cattle crossing our Western plains with moderate loads.

The steam engine requires no such care-

* Morin's Mechanics, New York: D. Appleton & Co. 1860, p. 348.

* Vide Steam Engines and Prime Movers: Rankine, chap. 3, p. 85.

ful limitation of working time. It can work twenty-four hours uninterruptedly as readily as a single hour. Ten hours a day would be, in most cases, made the daily working time of a road locomotive, the period being determined by the proper length of the working day of the driver, rather than by the capabilities of the machine.

The working time of the traction engine may therefore be stated to be, ordinarily, twenty per centum greater than that of the dray horse, and to be capable of indefinite extension when required.

The loss of working time by the horse through illness, at the farriery, etc., and that lost by the locomotive in the repair shop, are proper subjects for comparison; but it is difficult to determine them in the absence of reliable data. We may estimate these losses as equally affecting the two motors, with a probability that the correction of any error in such estimate may make a change favorable to the locomotive.

First Cost.—Comparing the first cost and running expenses of steam and of horse power, we may work from tolerably well established data. The list price of the Aveling & Porter road locomotive, experimented with at South Orange, is, delivered in New York, about $4,000.

The average cost of horses purchased by the Third Avenue Railroad in New York city, is now $157.50, and it would require more than twenty such horses to pull the load of the traction engine, while an addition of twenty-five per cent. must be made for the greater length of the working day of the locomotive. Twenty-five such horses would have a first cost of $3,937.50, to which must be added the large item of cost of harness.

The first cost of steam and of horse-power is, therefore, nearly equal, the difference being in favor of steam, leaving, also, on the side of the engine, the immense advantage arising from its ability to work longer hours when required, and indefinitely. The interests on these first costs also nearly balance each other.

Running Expenses.—The running expenses of the locomotive consist of cost of attendance, of fuel, oil and repairs, and of depreciation in value with use; those of horse power are attendance, food, stabling, sickness, and depreciation with age.

The cost of attendance upon the one engine and the twenty-five horses may be taken at $939 and $3,130, respectively, assuming each driver of the latter to be able to manage a six-horse team. The engine driver receives three dollars per day and the other men two dollars and a half, and there are 313 working days in the year.

The cost of fuel, oil, and incidentals, excluding repairs of the engine and its depreciation, may be averaged at $900 per year, in the vicinity of New York. This is somewhat higher than the cost of similar items on railroad locomotives in New York State.*

The cost of repairs and depreciation has been thus far so small at South Orange that it could not be estimated, but for the life of the engine, it will be likely to average something less than fifteen per cent. of the first cost, or in this case, $600 per annum. This we arrive at by an examination of railroad locomotive expenses,† as officially reported.

The total annual expense, therefore, of the traction engine referred to may be reckoned at $2,439 as a maximum figure, including cost of attendance. A similar estimate will give, for the annual expense of keeping one horse, very exactly $300, excluding attendance. In the year 1870, 10,315 horses in the State of New York cost for stabling, feeding, repairs to harness and shoes, etc., according to the official statements, $3,182,838.24, or $308.56 each animal. From this is to be deducted about eight dollars per head for receipts from sales of horses, leaving for annual expenses, say, $300 per horse. The expense account, excluding attendance, would be, for twenty-five horses, $7,500, as against $1,500 for a similar amount of steam power, *and including attendance*, $10,500, as against $2,439.

Referring once more to the expense account of the Third Avenue Railroad, we find it working more economically than the average as given above. This company employs an immense number of horses, buys its supplies in large quantities, taking advantage of the market, and is able to do much better than could any individual or smaller capitalists. The following data were kindly furnished by Mr. Charles S. Arthur:

* State Engineer's Reports.

† This is about the figure on good railroads in the United States; on British roads the range is from 10 to 25 per cent., averaging very exactly 15 per cent.

Average first cost of horses, per head,	$157 50.
Average price obtained when sold, (3½ years latter.)	65 00.
Cost of stabling, general expenses, and incidentals,	180 00.
Total annual expenses, including depreciation,	206 43.
Add to the above the cost of harness (not stated), say,	3 00.

The total annual cost of horse-power, for comparison, $25 \times \$209.43 = \$5,235.75$, to which we add $3,130 for drivers, and we make a total cost per year of $8,365.75 to be compared with $2,439, the total annual expense of the road locomotive capable of doing an equal amount of work.

The expense account when doing heavy work on the common road under the described conditions, by steam power, is therefore less than 25 per centum of the average cost of horse power, as deduced from the total expense of such power in New York State, while if we take for comparison the lowest estimate that we can find data for in our whole country, we still find the cost of steam power to be but 29 per centum of the expense of horses.

We may state the fact in another way: a steam traction engine, capable of doing the work of 25 horses, may be worked at as little expense as a team of six or eight horses.

Prospective.—Thus, thirty years after the defeat of the intelligent, courageous and persistent Hancock and his co-workers in the scheme of applying the steam engine usefully on the common road, we find strong indications that, in a new form, the problem has been again attacked and at least partially solved. It was formerly supposed that success in the transportation of passengers by steam on post routes would lead to the application of that motor to the movement of heavy loads and to agricultural purposes generally. When, after so long a trial, the experiment finally seemed to have failed of success, it was believed that steam could not be applied to heavier work on common roads. As we have now seen, however, it appears probable that the inventors of that day attacked the problem at the wrong point, and that, on the common road, the transportation of heavy loads by steam being accomplished with economical success, under ordinarily favorable circumstances, it may prove introductory to the use of steam in carrying passengers and light freight at higher velocities.

Having examined in detail the capabilities of the road locomotive, and determined the value of steam traction on macadamized roads, and having obtained the measure of its economic superiority over horse power, there remains to be considered the conditions which favor or retard its introduction, and to determine where it may be adopted without apprehension of failure.

One of the most important of the pre-requisites to ultimate success in the substitution of steam for animal power on the highway, is that our roads shall be well made.

As the greatest care and judgment are exercised, and an immense outlay of capital is considered justifiable, in securing easy grades and a smooth track on our railroad routes, we may readily believe that similar precaution and outlay will be found advisable in adapting the common road to the road locomotive.

It is undeniably the fact that, even when relying upon horse power, far less attention has been paid to the improvement of our roads than true economy would dictate. With steam power, the gain by careful grading and excellence of construction of the road-bed becomes still more important. The animal mechanism is less affected in its power of drawing heavy loads than is the machine. With the horse, a bad road impedes transportation principally by resisting the movement of the load rather than of the animal, while with the traction engine the motor is as seriously retarded as the train which follows it, andfrequently much more, on soft ground.

Steam, therefore, cannot be expected to attain its full measure of success on rough and ill-made roads; but where highways are as intelligently engineered and as thoroughly well built as those on which the trials at South Orange were made, or where nature has relieved the engineer and the road builder of the expensive work of grading, as throughout a very large extent of the western and southern portion of our country, we may expect to see the road locomotive rapidly introduced.

The earliest and most perfect success of the traction engine, and its probable successor, the steam carriage, may be expected to occur in those districts. Its great economical advantage over animal power, as exhibited above; its freedom from liability to become disabled by epizoötic diseases; its reliability under all circumstances, and the many other advantages which are possessed by the machine, are already securing its rapid introduction, despite the difficulties

arising from popular prejudice and unfamiliarity, from hostile municipal laws, and other existing obstacles.

We are learning that this motor, when it can be used at all, is comparatively inexpensive; that our roads are improved by it, and that the ancient idea of its conflicting with the interests of owners and workers of horses, is only a superstition.

We have found by our experience with steam fire engines, with the elevated railroad on Greenwich street, New York, and with railroads throughout the country, that the frightening of horses is but a temporary and a comparatively insignificant inconvenience. It would seem to the engineer that the natural obstacles generally supposed to stand in the way have, after all, no real existence.

The principal inconvenience that may be anticipated will probably arise from the carelessness or avarice of proprietors, which may sometimes cause them to appoint ignorant and inefficient engine drivers, giving them charge of what are always excellent servants but terrible masters. Nevertheless, as the transportation of passengers on railroads is found to be attended with less liability to loss of life or injury of person than their carriage by stage coach, it will be found, very probably, that the general use of steam in transporting freight on common roads may be attended with less risk to life or property than to-day attends the use of horse power.

This great economical revolution has now made a fair start, and is progressing with most encouraging rapidity. We may anticipate its complete success at no distant period. Meantime every member of the engineering profession may aid its progress by exerting a personal influence in favor of the improvement of our roads and the further improvement of the road locomotive, which has, as we have shown, at last assumed a practical shape, and has exhibited wonderful power. It is now at work in every portion of the civilized world, and the one establishment which constructed the engines above described is now furnishing employment to 1,000 working men, supporting a total population, probably, of 5,000 people.

Such a commencement having been made in a country like Great Britain, it is difficult to conceive how great may not be the future of this branch of industry when the valley of the Mississippi and our Western plains, the natural habitat of this motor, shall have become finally a principal seat of its manufacture as well as of its employment.

USEFUL FORMULÆ FOR CEMENTS.

From "The Journal of Applied Chemistry."

A good rubber cement may be prepared by dissolving one part india-rubber in two parts linseed oil, and adding to the solution a sufficient quantity of bole, say about three parts.

For amber and tortoise-shell, a cement is made by mixing together equal parts of mastic and linseed oil, and warming gently. This cement should be used warm.

To unite wood to wood, a thick solution of shellac in alcohol may be used. It is well to put a piece of fine gauze or crape between the broken surfaces of wood, and then press them tightly together until the cement becomes perfectly firm. Another good, durable cement for wood-work is made by fusing together shellac, mastic, and common turpentine, and adding some broken isinglass.

For attaching small objects to anything turned, a mixture of colophonium, turpentine, and yellow wax, with the addition of a little pulverized sealing wax, answers nicely. The cement sets quickly and holds well.

To fasten knives and forks in silver handles, we may use a mixture of two parts of melted black pitch and one part of fine brick dust. It must be used warm.

A varnish or cement to protect wood from the action of mineral acids, alkalies, and corrosive gases like chlorine, is made from six parts of colophonium and three parts of wood tar by heating together in an iron kettle on a furnace in the open air, and then stirring in four parts of fine brick dust. The varnish is applied with a brush while warm.

An excellent cement for glass is made by dissolving one part india-rubber in sixty parts of chloroform, then adding thirty-four of mastic, and letting it digest for a week at a gentle heat. This cement is also applied

with a brush, and is especially distinguished by its transparency.

Another cement for glass and porcelain is made by digesting pieces of isinglass in sixteen times their weight of water for 24 hours. The solution is evaporated to one-half, strained, and, while still hot, eight parts of alcohol is added, and at the same time a solution of one part mastic in six parts warm alcohol. One-half part of finely-powdered gum ammoniac is triturated in the warm solution until the whole mass is homogeneous. When used, both the cement and the object to be mended are warmed. This cement is highly recommended for its adhesive qualities.

GLUE AND GUM CEMENTS.

These are very tender and well adapted to mending ornaments. They resist the action of water and atmosphere. There are various kinds of these cements for bone, ivory, whalebone, mother of pearl, and precious stones.

One of these is made by dissolving 2 parts isinglass and 4 parts colorless glue in 60 parts water, evaporating to half its volume, then adding 1–15 part mastic dissolved in 1 part alcohol, and stirring in 2 parts zinc white. The surfaces are warmed when the cement is applied to them. This cement holds well, dries easily, and may be kept a long time in tightly-corked bottles.

For bone, ivory, whalebone, mother of pearl, etc., a cement with a beautiful gloss may be prepared as follows: Soak common cabinetmakers' glue in hot water, warm the jelly formed, add enough pulverulent slaked lime to give it consistency. Warm the object to be cemented, clean the surfaces carefully, apply the cement and tie the parts firmly together. In a few days it gets very hard. Even common glue, with pulverized chalk stirred in, makes an excellent cement for wood and metals.

For fastening leather to metal, the metal should be coated with a hot solution of glue, and the leather with a hot extract of nutgalls. Allow them to dry quietly, and they adhere well.

For porcelain, the well-known white of egg cement is best. To prepare this it is only necessary to stir the white of eggs into quite a stiff solution of glue, and then apply to the fracture.

A cement of gum for porcelain is made by pulverizing 4 parts of oyster shells and mixing intimately with 2 parts pulverized gum-arabic. The powder is kept in a well-stoppered bottle, and when needed for use is rubbed up with white of egg, or warm water, to a thick dough, applied to the object and dried by a gentle heat. Another cement for glass and porcelain is made from 8 parts well-burnt pulverized alabaster gypsum and 2 parts fine gum-arabic, mixed with water to a thick paste, and 40 to 50 drops of oil of turpentine added to an ounce of the cement.

CEMENTS FROM CASEINE.

For glass, porcelain, stone and wood, the very best cement is made of a suitable quantity of old cheese rubbed fine and mixed with water to a thick magma, and a fourth part of pulverized lime added.

A still stronger cement for the same purpose is made by slaking 1 lb. of quick lime in water, and mixing with ¾ lb. pulverized lime or sandstone and 1 lb. pulverized cheese. Before using, it is well to moisten the fracture or edges with warm water.

A so called caseine water glass is made as follows: The caseine of skimmed milk is separated from it by the addition of acetic acid filtered, and the acid washed out with water. The pure caseine thus obtained is mixed with six times its volume of concentrated water glass. This cement is thoroughly commendable, and well repays the trouble taken to make it.

An excellent cement for artificial meerschaum and one that may be used to give consistency to silk goods or to coat artifical flowers and court-plaster, to give more adhesiveness and firmness, is made by rubbing two to four parts of the above caseine with cold borax solution till a thick liquid is obtained that becomes clear on standing. This also renders goods water-proof.

WATER-GLASS CEMENTS.

For glass, earthenware, porcelain, and all kinds of stoneware, these cements are excellent. A cement for glass and marble is prepared by rubbing together one part of fine pulverized glass and two parts of pulverized fluorspar, and then adding enough water glass solution to give it the consistency necessary in a cement.

Water glass mixed with hydraulic cement to a thick dough makes a good cement for the edges and joints of stone and marble slabs. It is well to mix but little at a time, as it hardens very quickly.

LIME, GYPSUM, CLAY AND CEMENT, MIXED WITH WATER, OIL, OR BLOOD.

For cementing stone and for filling crevices in buildings, before they are painted, the masons use a cement made of fresh blood, slaked lime, brick dust, broken up coal ashes, hammerslag, and sand in all proportions. This excellent cement hardens quickly and offers great resistance to the action of the weather.

A lime cement for connecting water pipes, bathing tubs, etc.: a mixture of two-thirds fine brick dust, two-thirds unslaked lime, and two-thirds hammerslag, is made and stirred up with lye or hot oil to a stiff dough.

Another cement, intended to render Hessian clay retorts impenetrable, is obtained by rubbing freshly slaked lime into a concentrated solution of borax. The solution is applied with a stiff brush and allowed to dry, after which it is heated until the glazing begins to fuze.

Clay mixed with water and fresh warm blood, containing some unslaked lime, is used in Germany to close the joints in their stoves. The cement is applied while the stove is hot. Wood ashes, fire-clay and salt mixed with water is used for the same purpose. Fat and burnt clay, in equal proportions, moulded with water into a dough, is also used.

Plaster of Paris mixed with water and a cold solution of alum is an excellent cement for stoneware. It sets slowly, but becomes as hard as stone.

IRON CEMENTS.

Their essential constituents are iron filings or borings. By the addition of some common salt or sal ammoniac they are rapidly oxidized, and the escape of carbonic acid increases the volume of the cement and completely fills the crevices where it is put. An excellent luting or cement for the joints and crevices in iron surfaces, and for rendering tight cast-iron steam and water pipes and water tanks, is made of filings of cast iron. The filings are sifted to obtain those of the size of a grain of rice, and then rubbed with horse urine and one-half part sal ammoniac, well worked together, and an equal quantity of flowers of sulphur added. The mass is hammered until it gets warm, and then cold, and, finally, it begins to be brittle. In this condition it is put in the joints, and soon hardens. The surfaces where it is applied must be free from rust. Greasy and oily substances are most readily removed by rubbing with cotton dipped in benzine. The cement keeps best under water.

Another good iron cement is made by stirring five parts clay, one part salt, and fifteen parts iron filings together with vinegar to a magma. It will stand heat, and is used for bellows and air pipes.

OIL CEMENTS.

An excellent oil cement for porcelain and for luting of retorts, flasks, and porcelain evaporating dishes, is obtained when ordinary brick dust is powdered, sifted, and mixed with an equal quantity of red lead, and then rubbed, under great pressure, into old boiled linseed oil to a thick paste, which is mixed with coarse sand to the stiffness of cement. When a dish is to be covered with it, the paste is applied before the sand is put in, and the sand then strewn upon it. The dish is afterward exposed to a steady heat for a long time.

For larger vessels take six parts litharge, four parts fresh-burnt pulverized lime, and two parts white bole, and mix with cold linseed oil.

To fasten metallic letters to a smooth surface a cement is made as follows: 30 parts copal varnish, 10 parts linseed oil varnish, 6 parts crude oil of turpentine, 10 parts glue dissolved in a little warm water, and 20 parts pulverulent slaked lime. It is very pliant and soon hardens.

To unite copper and sandstone, take 3½ parts white lead, 3 parts litharge, 3 parts bole, 2 parts broken glass, and rub up with 2 parts linseed oil varnish.

As a polish for gravestones, basins, etc., a paint is made of 9 parts of finely sifted and burnt brick clay and 1 part litharge, mixed with a sufficient quantity of linseed oil.

For connecting cast-iron water pipes, 12 parts Roman cement, 4 parts white lead, 1 part litharge and ½ part colophonium are pulverized and mixed; from 2½ to 3 lbs. of it is triturated with old linseed oil, in which is boiled 2 ounces colophonium.

Another for the same purpose is made of equal parts of burnt lime, Roman cement, potters' clay, and clay, separately well dried, finely ground, sifted, well mixed, and triturated with linseed oil. Common lead lute for stopping openings in apparatus is best made from litharge and red lead mixed with

old boiled oil. In all cases the surfaces must be clean. They stand well under water.

As lead lutings are somewhat expensive, the following is recommended: Take 2 parts red lead, 5 parts white lead, and 5 parts of the finest clay, and mix with boiled linseed oil.

A good oil cement for wood, especially for antique carvings, is made of 1 part pulverized slaked lime and 2 parts rye flour, mixed with linseed oil varnish. It takes any desired color and polish.

To make water holders tight we may use pulverized slaked lime and cod-liver oil.

A cement to make chemical apparatus tight can be prepared from oil cake or pressed almond cake rubbed with water.

MISCELLANEOUS CEMENTS, ETC.

Furniture Polish.—Moisten 120 parts beeswax with oil of turpentine, and add 7.5 parts finely pulverized resin, and enough aniline red to give the desired mahogany color.

Oil Cement.—One hundred parts red lead, 250 parts white lead, 200 parts pipe clay; mix with boiled oil.

Water Cement.—One hundred parts slaked lime, 190 parts brick dust, 160 parts sand, 50 parts blacksmiths' dross, 50 parts powdered lime; mix with water.

Another.—Six hundred parts iron filings, 100 parts ignited sand, 100 parts powdered slaked lime; mix with water.

Iron and Blood Cement.—One hundred parts pulverized lime triturated with bullock's blood, 200 parts cement, and from 5 to 10 parts iron filings.

ON THE RESISTANCE OF IMMERSED HULLS.

Contributed by C. DELÉVAQUE, ancien élevè de l'Ecole Polytechnique.

What power should be given to the engine of a ship to obtain the required speed? The solution of this problem has been made many times, but without a satisfactory answer.

The question is therefore an open one. I shall attempt to prove the solution by a different method than employed by those who have preceded me, but profiting from the known results of the experiments already made in determining the constant values belonging to all study of practical problem.

Value of the motive power. The problem of the resistance of a vessel must be expressed as follows:

A vessel is moved in smooth water by an inextensible thread without weight; what is the tension of this thread when the vessel sails V metres a second with an uniform motion?

T_m denotes the motive power expended during a second.

$$T_m = F\,V.$$

F denotes the force expended,

V the speed.

As the vessel is propelled uniformly

$$T_m = T_p \quad . \quad . \quad . \quad (1.)$$

but T_p has many parts:

1°. T_f power of the friction of the immersed surface; T_f is proportionate to the speed V of the ship and to the surface Σ^e of the immersed hull; the value of T_f is not the same when the ship is built of iron or of wood with copper sheeting,

$$T_f = K\,\Sigma^e\,V,$$

and K belongs to the nature of the immersed surface.

2°. T_N represents the power expended forward, to cleave the water.

The mass of water required to be displaced by the movement is indicated by

$$\frac{1.025}{g}\,S\,V,$$

for S V represents its volume, S denotes the area of the immersed dead flat cross-section.

This mass $\frac{1.025}{g}\,S\,V$ is displaced V′ metres,

and $T_N = \frac{1.025}{2\,g}\,S\,V\,V'^2$.

V′ is a function of V and of the elements of the vessel.

Let us consider what occurs forward when a ship sails: the water rises more or less at the sides, according to the speed and the sharpness.

A wave produced by the movement of the water which is thrown back follows the ship and is continued in an oblique direction to the ship's course.

$$V' = f(V)$$

and by explaining

$$V' = A' + \alpha' V +$$

if $V = 0$, $V' = 0$, then $A' = 0$.

If we take only the first term

$$V' = \alpha' V$$

using n''_1 as the exponent of the parabolic rule followed by the areas of the forward sections of the vessel, which has a length L_1, α' increases with n''_1, α' increases, in accordance with the value of $\frac{l}{L_1}$ ($2l$ denotes the breadth of beam); we may then write

$$\alpha' = \sqrt{K_1}\, n'' \frac{l}{L_1}$$

then

$$V'^2 = K_1 \frac{n''^2_1 l^2}{L_1^2} V^2$$

$$T_N = K_1 S \frac{1.025}{2g} \cdot \left(\frac{n''_1 l}{L_1}\right)^2 V^3.$$

3°. T_{AR} denotes the motive power expended aft by the water which fills the track opened by the vessel; this power is positive and varies for the same vessel if she is moved either by screw, or wheels, or sails. The mass of water displaced is $\frac{1.025}{g} S V$; it has a speed V'', and

$$T_{AR} = \frac{1.025}{2g} S V V''^2.$$

By studying a jet of water in its active trajectory, the pressure on the vessel is increased by the curve of the trajectory.

$$V'' = f_2 (V)$$

$$V'' = A'' + \alpha'' V + \beta'' V^2 +$$

if $V = 0$, $V'' = 0$, then $A'' = 0$.

Experiments, however, prove that V'' increases with n'' and $\frac{l}{L_3}$ (L_3 is the length of the after part).

As the screw aspirates water aft, it augments the speed, and we may indicate by N the number of revolutions per minute of the screw.

$$V'' = \sqrt{K_3}\, n''_3 \frac{l}{L_3} V \left(1 + \frac{N}{60}\right)$$

and

$$T_{AR} = K_2 \frac{1.025}{2g} S V^2 \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \frac{N}{60}\right)^2$$

This formula answers as well for paddles as screw; if, in the second case, water is aspirated by the screw, it is thrown away by the paddles.

As regards the sailing ships, $N = 0$.

4°. T_f denotes the power lost in eddies forming aft; this term is proportionate to $S V$, for the mass moved has kept away some living force (*vis viva*) beyond the ship.

V''' denotes the mean velocity of this water.

$$V''' = f_3 (V)$$

and we have as before

$$V''' = \alpha''' V.$$

α increases with N, n''_3 and $\frac{l}{L_3}$. V''' varies with the elements of the propeller which increases or diminishes the eddies.

We have

$$T_f = K_2 \frac{1.025}{2g} S \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \beta \frac{N}{60}\right)^2 V^3$$

β is dependent only on the propeller.

By replacing T_m and T_p by their value in the equation (1), we obtain the general formula

$$F = K x^c + K_1 S V^2 \frac{1.025}{2g} \left(\frac{n''_1 l}{L_1}\right)^2 -$$

$$K_3 S V^2 \frac{1.025}{2g} \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \frac{N}{60}\right)^2 +$$

$$K_2 S V^2 \frac{1.025}{2g} \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \beta \frac{N}{60}\right)^2$$

This formula agrees with the results of the most careful experiments the trials of the "Elorn" have settled. In the general expression of the resistance the term answering to the friction is independent of the speed, and the resistance of the vessel varies with the kind of screw employed.

CALCULATION OF THE CONSTANTS.

The trials of the "Elorn" give us the power to calculate K_1, K_2 and K_3; we shall have also the value of K for a wooden bottom sheathed with copper, and we shall know how β varies with the elements of a screw.

Six experiments were made in smooth water, with a three-bladed screw of $1^m.80$ diameter; the pitch was $3^m.15$, and the fraction of the pitch 0.25.

These interesting results are shown in the next table.

F.	$\frac{N}{60}$	V.
k.		*m.*
362.05	1.1946	3 299
465 08	1.3533	3.675
630.08	1.5158	3.992
699.41	1.5984	4.168
858.08	1.7842	4.483
946.70	1.8283	4.699

In these experiments S was constant, its value was $7.4449 m^2$; and for the immersed hull of the "Elorn" we have

$$L_1 = 13^m. \qquad L_3 = 12^m.$$
$$n'' = n''_1 = n''_3 = 1.1$$
$$2l = 4^m.88 \text{ and } \Sigma^c = 150 m^2,$$

the general formula may be merely

$$\phi = K\chi + K_1 \frac{1}{L_1^2} - K_3 \frac{1}{L_3^2}\left(1+\frac{N}{60}\right)^2 + K_2 \frac{1}{L_3^2}\left(1+\beta\frac{N}{60}\right)^2$$

by denoting

$$\phi = \frac{F}{\frac{1.025}{2g} S l^2 V^2 n''^2} \qquad \chi = \frac{\Sigma^c}{\frac{1.025}{2g} S l^2 V^2 n''^2}$$

Let us calculate the values of the functions ϕ and χ.

V.	ϕ	χ
m.		
3 299	11.8714	4.9184
3 675	12 2888	3.9635
3 992	14.1095	3 3590
4.168	14.3673	3.0813
4.483	15 2366	2.6635
4 699	15.3003	2.4242

This table shows the errors of the results of the trials; these errors are evident if we draw two arcs, the first having φ as ordinates, and the second χ; the values of V are the abscissas.

With these arcs we can correct the results, and the following table represents what must represent ϕ in the calculation of the constants.

V.	ϕ
m.	
3.299	12.39
3.675	13 29
3 992	14 20
4.168	14.60
4.483	14.80
4 699	15.00

We establish with these figures the six following equations by putting

$$K_2 \beta = K_4$$

and

$$K_2 \beta^3 = K_5$$

We infer from this

$$\beta = \frac{K_5}{K_4} \text{ and } = K_2 \frac{K_4^2}{K_5}$$

$$12.39 = 4.9184\ K + 0.00591\ K_1 - 0.033446\ K_3 + 0\ 00694\ K_2 + 0\ 01659\ K_4 + 0.00991\ K_5.$$
$$13\ 29 = 3\ 9635\ K + 0.00591\ K_1 - 0.038458\ K_3 + 0.00694\ K_2 + 0\ 01879\ K_4 + 0.012718\ K_5$$
$$14.20 = 3.359\ K + 0\ 00591\ K_1 - 0.043053\ K_3 + 0.00694\ K_2 + 0.02105\ K_4 + 0\ 015993\ K_5$$
$$14\ 60 = 3\ 0813\ K + 0.00591\ K_1 - 0.046886\ K_3 + 0\ 00694\ K_2 + 0\ 0222\ K_4 + 0\ 017742\ K_5$$
$$14\ 80 = 2\ 6635\ K + 0.00591\ K_1 - 0\ 051916\ K_3 + 0.00694\ K_2 + 0\ 02409\ K_4 + 0.020885\ K_5$$
$$15.00 = 2.4242\ K + 0.00591\ K_1 - 0.05555\ K_3 + 0.00694\ K_2 + 0.02539\ K_4 + 0.023213\ K_5$$

These equations are verified by the following values:

$K = 4$ $\qquad$ $K_1 = 20874$
$K_2 = 6296$ $\qquad$ $K_3 = 3474$
$K_4 = 1630$ $\qquad$ $K_5 = 422$

and

$$\beta = 0\ 259.$$

By placing these values in the general formula, we have for the resistance of any immersed hull, the expression

$$F = 4\,\Sigma^c + 20874\ S\ V^2 \frac{1.025}{2g}\left(\frac{n''_1\, l}{L_1}\right)^2 - 3474\ S\ V^2 \frac{1.025}{2g}\left(\frac{n''_3\, l}{L_3}\right)^2\left(1+\frac{N}{60}\right)^2 + 6296\ S\ V^2 \frac{1.025}{2g}\left(\frac{n''_3\, l}{L_3}\right)^2\left(1+\beta\frac{N}{60}\right)^2$$

Σ^c and S are expressed in square metres, l, L_1, L_3, and V in metres and F in kilogs.; N is the number of revolutions per minute of the propeller.

This formula must be used only for a wooden hull sheathed with copper.

VARIATIONS OF β.

β varies with the elements of the propeller.

We shall consider only the case of screws, for we have no results of another motive power; we may say that the nearer the screw is a plane perpendicular to the axis, the greater the value of β.

The trials of the "Elorn" were made with a screw of the same diameter and fraction of pitch.

We have

$$\beta = f(m, H).$$

H denoting the pitch and m the number of the blades.

If m is constant, we deduce

$$\beta = \phi(H).$$

Let us calculate β for the different values of H which were used. The three-bladed screw gives

F.	S.	V.	$\frac{N}{60}$	H.
k.	m^2.	*m*		*m.*
1101.45	7.4946	5.015	1 8511	3.60
1124 44	7.3704	5.109	2.2038	2 78
894.42	7.4449	4.603	2.2433	2.25
1004.87	7.3952	4.829	2 8060	1.80

With the numbers of this table β is calculated.

These values are in the following table.

β.	H.
	m.
0 185	3.60
0.259	3 15
0 33	2.78
0 336	2 25
0.463	1 80

$$F-600 = S V^2 \left\{ 46.549 - 9.0324 \left(1 + \frac{N}{60}\right)^2 + 16.3696 \left(1 + \beta \frac{N}{60}\right)^2 \right\}$$

By drawing an arc with the abscissas H and the ordinates β, we have between these quantities

$$\beta H^2 = 2.5.$$

The pitch is supposed constant, let us vary the number of blades, we deduce from the following table the relation

$$\beta m = 0.6.$$

m.	F.	S.	V.	$\frac{N}{60}$	β
	ch.	m^2.	*m.*		
6	1083 71	7.4946	5 072	1.8001	0.16
5	1075.69	do.	4.995	1.7814	0.144
4	1165.84	7.5443	5.099	1.8275	0.175
3	1101 45	7.4946	5.015	1 8511	0 212
2	1029 86	7.4699	4.869	1.8771	0.291

but

$$\beta = A \frac{1}{m H^2}$$

and

$$A = 0.6\,(3.60)^2$$

or

$$A = 7.776$$

and

$$\beta = 7.776 \frac{1}{m H^2}.$$

If d is the diameter of the screw and I the fraction of pitch, we have

$$\beta = B d^2 I. \frac{1}{m H^2}$$

and for the "Elorn,"

$$d = 1^m.80 \text{ and } I = 0.25$$
$$B d^2 I = 7.776$$
$$B = 9.6,$$

and

$$\beta = 9.6 \frac{d^2 I}{m H^2}$$

in the limits of the experiments.

RESISTANCE OF THE IRON SHIPS.

The following formula is not intended for iron ships.

$$F = 4 \Sigma^c + 20874 S V^2 \frac{1.025}{2g} \left(\frac{n''_1 l}{L_1}\right)^2 - 3474 S V^2 \frac{1.025}{2g} \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \frac{N}{60}\right)^2 + 6296 S V^2 \frac{1.025}{2g} \left(\frac{n''_3 l}{L_3}\right)^2 \left(1 + \frac{N}{60} \frac{d^2 I}{m H^2} 9.6\right)^2$$

With iron the coefficient of Σ^c is greater than 4.

We will further settle it by comparing the results of the trials of the iron-clad the "Héroine" and the other wooden frigates of same dimensions and power.

STEAMSHIP PERFORMANCE.

The power f expended by the engine measured with the indicator is decomposed as follows :

1°. t transmitted power.

2°. f power expended in friction.

3°. v power lost by vibrations.

The trials of the "Elorn" give us the proportion of those three kinds of power which are contained in f.

$$f = t + f + v.$$

f is given by the diagrams and the number of revolutions.

f is proportionate to the velocity C N ;

c denotes the stroke of the piston and N' the number of revolutions per second of the engine ; f is also a function of the pressure; M. Joëssel's experiments havo shown it.

We have then

$$f = K C^2 N'^2 (p D^2)^{0.6} p D^2$$

t is given by Taurine's dynamometer. The greater the mass of the engine, the smaller is the power lost by its vibrations.

If D is the diameter of the cylinder and A the number of cylinders of the engine, we have

$$v = K' \frac{N'^2}{A D^2 C}$$

But in the engine of the "Elorn."

$$c = 0^m.50$$
$$D = 0^m.60$$

and

$$A = 2.$$
$$f = \frac{60 A D^2 c N'}{21.015} p.$$

f.	t.	N'.	p.
ch.	*ch.*		*cm.*
132.67	105 56	0 98	132.16
93.45	74.15	0.87	104.85
57 51	47.21	0.76	73 89
41.12	31.83	0.66	60.37
31.79	23 80	0 60	51.48

We have in this table the elements of three equations, and we fix

$$K = 0.06 \qquad K' = 7.4131.$$

The general formula is then

$$f = t + 0.06\, c^2\, N'^2\, (p\, D^2)^{1.6} + 7.4131\, \frac{N'^2}{A\, D^2\, c}.$$

For each kind of engines we should have an analogous formula.

ARMOR OR NO ARMOR.

From "Engineering."

The growing necessity for still heavier armor upon ships of war, and the popular disbelief in their ability to carry it, are bearing the fruits to which we lately called attention, in the shape of a powerful agitation for the abolition of armor plating, and for the building of a class of unarmored "floating gun carriages," in which speed shall be the first consideration. The fact that this idea is in evident favor with the "Times," will not be reassuring to those who remember, though they would gladly forget, how largely the building of the luckless Captain was due to the pertinacious advocacy of that journal. As the theory has, moreover, a considerable following in Parliament, there is only too much reason to fear another mischievous agitation, ending perhaps in the country being saddled with a number of nearly useless vessels, with possible results almost as lamentable as those which attended the brief history of the low free-board delusion.

Not long ago the ball was again set rolling by Colonel Strange, who revived the old suggestion to employ numerous small unarmored ships, of great speed, each carrying one heavy gun, in place of the one heavy iron-clad whose suppression is supposed to provide the funds for building them. This suggestion he jumbled up in a curious manner with the proposal (which he supposed to be original, though it was previously made in "Engineering") to mount guns upon the Bessemer principle of controlled suspension—an improvement which, if made at all, would be just as effectual in the case of iron-clads as in the case of unarmored ships. Nevertheless, Col. Strange took it for granted, without argument, that the command of a perfectly steady gun platform—in other words, a greatly increased chance of hitting the enemy—would be all in favor of his floating gun-carriage, and against the iron-clad, and upon this assumption alone based his proposals. As there is a certain novelty in this view of the case, it will be well to state the grounds of our dissent from it.

So long as it is assumed that the chances are much against hitting the object fired at, there may be reason in multiplying guns in several vulnerable ships, as their chance of hitting the one iron-clad is increased, while her chance of hitting any one of her adversaries is small. But if hitting what you aim at is made a certainty, through Mr. Bessemer's invention or any other means, the several vulnerable ships may expect to be sunk in detail before they can damage the armored one to any serious extent. It is the supposed difficulty of hitting them, which is usually made the strongest point in their case; take this away, and they have no case left. That the principle of controlled suspension can be applied to even greater advantage in a large ship than in a small one is tolerably certain. In the large ship the vertical motion is less, and the angular motion in most cases slower, while the additional weight due to the proposed system of mounting—a matter worth consideration in a small vessel—would be hardly felt. Its success would therefore strengthen, and not weaken, the position of the iron-clads as compared with unarmored ships. However, we will waive this point, and will simply put aside the Bessemer principle of mounting guns, as not relevant to the question of armor or no armor. Indeed, it is only right to remark that the necessity for any such arrangement may fairly be doubted, in view of the extraordinary steadiness of all the later iron-clads. The suggestion was only made by us as a refinement which it was probably worth while to try—say upon one of the turrets of the new ship to be built at Portsmouth.

The question of armor or no armor, it is worth noting, is scarcely ever raised except by landsmen, by people who cannot appreciate the difference between an artillery experiment on shore and the conditions of a combat afloat. Given a 35-ton gun in each of two vessels, one unarmored, and the other carrying armor which that gun (firing at a similar target ashore) is able to pierce, and they jump to the conclusion that the armor is a useless encumbrance, forgetting that while only one hit in twenty, perhaps, will lead to penetration of the iron-clad, the unarmored ship will be pierced by every shell which strikes her. Another very important point, constantly overlooked, is the fundamental difference of weapons with which the two classes of ships must fight their battles notwithstanding the nominal equality of their 35-ton guns. The unarmored ship, having to pierce armor, is compelled to use either solid shot, or a class of shell differing but little from shot, and producing almost as little effect inside the vessel it penetrates. The iron-clad, on the other hand, bound by no such restriction, uses "common" shell, or such a modification of it as will insure getting through the (say) one-inch skin of her enemy. In other words, every hit scored by the iron-clad means the landing of a perfect mine of gunpowder within the body of the unarmored ship, and an injury out of all proportion to what the latter is able to cause in return, even when able to strike fair and hard. This capacity of very large guns for throwing common shell with immense bursting charges, at long ranges, is of great importance, because it gives armored ships an advantage over unarmored ones, which can never be taken from them. Of course it will be retorted that the unarmored ship is meant to be extremely fast and small, and therefore difficult to hit, while the iron-clad's attention is to be divided amongst several; perhaps also that she is to be so subdivided that she will bear penetration without serious injury. On the last point we will only remark that we disbelieve in any system of cells applied to the wind and water region of a ship. Had they nothing but shot to deal with, they might answer, but against large common shell with heavy bursting charges they will be useless. Moreover, in a small ship the cellular system cannot possibly be applied, except in the most partial way. As regards speed and smallness of target, we believe it to be purely a landsman's idea that ships are to fight while performing a kind of mad war-dance—this is what is usually represented—too fast for the gunner's eye to follow. The advocates of the penny steamboat style of warfare expect their little prodigies to fight like Jack the Giant Killer, and appear prepared to endow them with powers of hopping and skipping and twisting about at least equal to those of a man. These gentlemen never seem to be aware that the pirouettings of the "small and swift" must sooner or later bring them within reach of the big guns of the iron-clad; that they must come within reach at least every time they fire themselves; that the end-on position, so much affected by them, is the worst possible preparation for escape, however advantageous for attack; and that even a 1000-ton steamer, especially if rigged and sparred, makes a very fair target, though at a good distance. Sailors know all these things, and therefore we rarely hear doubts about armor from them. In fact Captain Sherard Osborn—the most practical of sailors when he will consent to be fair—wrote some excellent words on this very matter a little while ago. The splendid and costly Hercules, with her 6-inch armor on the battery, was, he said, but an imposture as a fighting machine, "but God help the unarmored ships that come against her."

But *the* argument against the proposal to meet iron-clads with numerous heavily armed swift and small vessels, lies in the simple statement that such vessels are impossible. You cannot have vessels, found and fitted as cruising men of war, which shall be both fast *and* small. Such ships exist only in the brains of their advocates, and are as mythical as the Flying Dutchman. Yet smallnes is the essence of the scheme, which turns upon the number of unarmored vessels which can be got for the cost of one iron-clad. That this will be quite a little fleet is taken for granted. After reading Colonel Strange one might almost conclude that the present Channel steamers have merely mistaken their vocation, and that, when thrown out of work by Mr. Bessemer, they have but to apply to him to be brought out in the new character of formidable men of war, "with a Bessemered (*sic*) gun in the bows." Who knows but they may avenge themselves on his colleague Mr. Reed, by sinking the Devastation? At any rate, if the little Channel steamers are not to enter on this more glorious existence,

there are heaps of "swift merchantmen" who may—just a "Bessemered" gun in the bows, and the thing is done. Of course they are also "small" merchantmen.

The first quality of these formidable small craft is to be speed, exceeding that of the iron-clads, that is a speed of certainly over 15 knots. It will be instructive, therefore, to see to what size unarmored vessels of this speed usually run. The first we suppose we ought to quote, is Mr. Thorneycroft's famous launch Miranda, which does 17 knots upon *very* small dimensions, but which, unless it be worth while (to use Colonel Strange's new verb) to "Bessemer" a punt-gun, is ill adapted to mount artillery in the bows, and is hardly suitable for general sea service. Of still greater speed are the Queen's yacht and the Holyhead steamers; but all these are of more than 2,000 tons burden, and owe their speed in part to a lightness of equipment which is out of the question in a war vessel. In America, the wooden sloops of the Wampanoag class are *said* to have reached 17 knots, but they are of 3,000 tons burden, and are so crammed with engines that they have hardly any room for coals, while their power to carry even one 35-ton gun without a complete change of structure and design is very doubtful. They might be guaranteed to shake themselves to pieces in a week's full steaming, and altogether would be most unsatisfactory vessels to bring against iron-clads—an enterprise never contemplated by their designer, who gave them their high speed expressly to enable them to run away with dispatch. Turning now to our own navy, we find the fastest ship is the unarmored Inconstant, who before she was half spoiled by the addition of ballast that never ought to have been put into her, gave 16¼ knots, by far the highest speed ever got from an efficient man of war. As she represents what the Wampanoag ought to be, and is, as stated, an efficient sea-going ship, carrying a proper proportion of coal and sail power, and built of suitable strength to stand high speeds without injury, it is not surprising to find that she is of over 4,000 tons burden, or within 1,000 tons of the Monarch, and 400 tons of the Devastation! Excluding the Wampanoag class she is the only unarmored war-ship in the world of a speed greatly exceeding that of our best iron-clads, and yet, for her speed, she is probably not a ton too large. As to the supposed fleet of such vessels in lieu of one iron-clad, the truth is that about five might be built for the cost, not of one Monarch, but of three; or for the cost of four Devastations. Five Inconstants against four Devastations! But as the Inconstant could, no doubt, carry two 35-ton guns, and may be said to have unnecessary speed for the purpose of engaging the Devastation, or even the (intended) 15 knot Fury, we will seek lower down for a vessel of the required power. We find it in the Active and Volage class of iron corvettes, which give something over 15 knots, and which might, no doubt, be fitted to carry one 35-ton gun each, though it would require careful design. Here is the type of vessel indicated, and its tonnage is 2,300, while its cost, roughly, is a third as much as the Devastation, and a fourth as much as the Monarch or Fury! Below this there is absolutely nothing in the navy which steams 15 knots, and we are certain there is nothing in the merchant service, which is also fit to mount a large gun. Merchant steamers, as a rule, are comparatively slow; and even the great ocean mail steamers, of not less tonnage than the Active, fall very far short of her in speed; 13 to 14 knots is a very high speed for them at the mile. Two thousand tons, it may safely be assumed, is the very smallest size upon which the required vessels can be built, and this is probably an under-statement, while the number which can be built for the cost of one Fury or Monarch is at the most four—these four carrying amongst them precisely the same gun power as the one iron-clad. (The Monarch was designed for 25-ton guns, but might equally well have been built to carry 35-ton, or even larger weapons.) They will be unfit, from lightness of build, to be used as rams; they will cost twice as much as the iron-clad for crew and repairs, and more than twice as much for coals; and in the hour of battle they will fall an easy prey to her. They would do the same, in our opinion, though their numbers were doubled, and though they met the iron-clad (we assume the Fury as the enemy, not the Monarch), with eight guns to four, and represented an expenditure of twice the money. It is suggestive of the amount of knowledge brought to bear upon this subject by writers like Colonel Strange, that in one of his letters to the "Times" he spoke of the addition of armor to the bows of his "small and swift" fleet as a matter of detail not worth discussing. We need

hardly say that it would so revolutionize his designs, or rather his fancies, that he might think himself lucky if he got two, not four, of his "small" craft for the cost of a Fury. Any such addition would simply end in an attempt to meet good iron-clads by bad ones.

The simple question at issue is—how many one-gun ships, of suitable speed, but no defensive power, can be built for the cost of one Fury? Col. Strange supposes many; we say few, for the type of ship he imagines is impossible, and cannot be made possible by improvements in the mode of mounting guns. In short, the whole scheme of the small-and-swift ship people rests upon a fallacy, upon the supposition that they can use ships which have no existence, and which cannot exist, and which, even if they existed in the numbers supposed, would utterly fail to do the work in view.

STRAINS ON RAILWAY AXLES.

From "The Engineer."

The last impression of the "Annuaire" contains a paper on railway axles, by M. F. Matthey, C.E., which deserves some attention. M. Matthey takes the view that the adoption of the cylindrical as the correct form for an axle, however much in accordance with purely theoretical principles, is contrary to the conditions prevailing in practice. On the assumption that the strains were simply vertical ones, and equal in amount upon each journal, and the axle was maintained in a constant horizontal position, the cylindrical would be the proper form to employ for that part of the axle situated between the bearings on the wheels. Provided the vertical pressures on the journals are equal, the maintenance of the axle in a uniformly horizontal position implies that the reaction of each rail is also equal. Omitting all consideration of curves, in which the superelevation of the outer rails destroys the horizontality of the axle, it is evident that one rail may sink more than its opposite neighbor, and that the joints are not so perfectly laid as to permit of the desired equality in the separate reactions. So far as the strains are concerned, the axle, or rather one-half of it, may be divided into three parts. They are respectively the part lying between the centre line and the nave or boss of the wheel, the part bearing upon or secured to the wheel, that is, in the wheel bed, and the part comprising the journal, or that which supports theoretically one half of the weight carried by the pair of wheels. The proportions of these several parts very materially affect the strength of the axle. Under the conditions M. Matthey shows that the bending moment at any part of the axle is directly proportionate to the distance between the centre of the journal and the centre of the rail, since the latter is supposed to represent the point at which the vertical reaction originates. This distance represents the leverage with which the vertical pressure acts on the axle. This strain is constant throughout the entire length of the axle, and would therefore indicate that the transverse section at any point is a constant, and that the true form is the cylindrical. The deduction from these premises, in which the weight of the axle itself is neglected, leads to the inevitable conclusion that a cylindrical axle being weakest in the middle, ought to break at that point. But experience has long ago proved that cylindrical axles do not break at the centre, but at some point situated either in the journals themselves, or just behind the boss of the wheel. Since the section is uniform, these parts must be more strained than those more contiguous to the centre, and, consequently, the central sectional area may be reduced and the strength of the whole axle remain unimpaired. If this be done the form of the axle is no longer that of a cylinder, but that of a double truncated cone. The object of adopting any particular form either of an axle, a girder, or other example of construction, is to obtain the one which will be equally strong at every point, whatever may be the difference in the amount of the relative strains at those points. It was the acknowledgment of this fact, and the endeavor to reduce it to practice, which led to the extended use of iron and the scientific treatment it has received in all its various applications, at the hands of engineers of modern times.

The suitable form to give an axle was arrived at practically, or, in old phraseology, by rule of thumb, before it was determined by analytical reasoning and investigation. Assuming that the normal condition of a-

fairs is represented by the coincidence of the centre of gravity of the load upon a carriage or wagon, with the vertical axis passing through the centre of the axle, that the two springs are equally weighted, and, consequently, the vertical pressure upon the journals equal to one another, it is nevertheless plain that this is a state of equilibrium which cannot long continue. Whatever may be the description or condition of the road upon wnich the axle runs, the vertical and horizontal shocks, which must occur in a greater or less degree, will speedily subject it to strains varying both in locality and intensity. Everyone who has travelled upon railways is well aware of the violent jerks which the carriage and its occupants undergo when travelling at a high, or even a medium velocity. These are principally felt when the train is passing crossings and points, and these are the very shocks which subject the axles to severe and sudden strains. The cause is not of so much consequence as the actual result, and if from any cause one wheel of the pair is subjected to a greater vertical reaction than the other, the vertical pressure upon one of the journals will be proportionately greater than that upon the other. The lateral motion of carriages on a railway will produce this effect, and the practical result is that the axle breaks—not at the centre, as would be the case under the normal condition already referred to, but at a point behind the boss or nave of the wheels. Of itself this fact is quite sufficient to demonstrate that, in practice, the cylindrical, or form of equal sectional area, is not the correct one to adopt in the case of the axles of railway vehicles. It is the consideration of this cause, which justifies theoretically and practically the employment of the truncated cone, which is now generally used on railways both at home and abroad.

This second cause of fracture is the horizontal jerk brought upon the flanges of the wheels, by the play or see-saw motion subsisting between them and the rails, which imparts the vibrating or oscillating motion to the carriages. The pressure upon the two journals thus becomes unequal, and the various cross sections of the axle are unequally strained in a corresponding manner. The part immediately behind one of the wheel bosses is strained to a maximum, while that in a similar position with regard to the other wheel is affected in a manner exactly the reverse. The bending moments produced upon the axle, at the centre or any other point, by the horizontal shocks, are invariably greater than those resulting from shocks of a vertical character. The increase in strain due to these last alone, has, according to M. Matthey, been determined by experiment to be so much as nearly 50 per cent. of the normal pressure.

To arrive at an accurate determination of the correct form for an axle, or, in other words, to ascertain the relative diameters of the different cross sections, it is necessary to take into consideration all the forces which are either separately or conjointly brought to bear upon it. When the flange of a wheel strikes against the rail, there is at once a horizontal force developed parallel to the length of the axle, which tends to push it and the load upon it towards the centre line of the track. At the same moment the wagon and its contents act in precisely the contrary direction, and tend to move towards the outside of the metals, so that the total strain upon the axle is the sum of the two forces, namely, the vertical load upon the journals, and the horizontal reaction of the wagon and its contents. Altogether there are six forces acting upon the axle. They are the two pressures acting upon the journals, the two reactions of the rails transmitted through the wheels, and the two horizontal forces. Under the influence of these forces the strain upon the axle is not confined merely to that of a bending moment, but is sometimes of a tensile and sometimes of a compressive nature, and is developed throughout the length of the axle. The effect of unequal lifting or yielding in the two wheels is to cause alteration in the position of the axle, and experiments have demonstrated that this inequality of motion produces different bending moments in the various sections of the axle, especially in the section situated immediately behind the wheel-bed, which may be regarded as the dangerous section. If the half axle, or the length between the centre and the middle of the bearing in the wheel, which point may be considered to be situated in the same vertical plane as the centre of the rail, be divided into five equal parts, and the bending moment at the centre of the axle be represented by unity, that of the remainder will vary from 1.13 to 1.65, the constant difference being 1.3. The corresponding diameters at these points will be 1.04,

1.08, 1.12, 1.15, and 1.18, the diameter at the centre of the axle being equal to unity. The diameter of that part of the axle which bears upon the wheel might be the same as that of the part outside it, that is, equal to 1.15 instead of 1.18, if the junction between the axle and the bearing were perfect. But as this is not always the case, it is judicious to enlarge it to the full amount. The dangerous section is that at which the diameter is represented by the proportion 1.15, and if that ratio be adopted at that point, and the diameter gradually diminished to 1.006 at the centre, the axle will have the form of a simple, cone which will differ in no appreciable manner from the theoretical form.

From the foregoing reasoning it is evident that every cylindrical axle which is of the requisite strength, may be replaced by another which would retain the same diameter at the dangerous section, but be reduced to 0.875 of that diameter at the centre. While equally strong with the original axle, this improved form would be very much lighter.

M. Matthey favors the use of cast-steel axles. When of good quality this material will safely stand twice the strain of wrought iron, and its bending and breaking moments will be in the same proportion. Calculating from these data, the diameter of a steel axle compared with that of a wrought iron one, will be as four to five, and its weight only five-eighths of that of the other. Another advantage of employing this material is that the diameter of the journals may be diminished in the ratio of 0.706. Moreover a steel journal will bear a greater pressure per square inch of surface without heating than one of iron. The result of using a smaller sized journal is to diminish the haulage, which in every vehicle varies directly as the proportion between the diameter of the journals and that of the wheels. The weight of a steel journal is about three-quarters of that of an iron one. By the adoption of steel axles there is no necessity for making the wheel-bed, and consequently the nave of the wheel, so long. The length of this part of an axle has not much influence upon the strength of it, provided the diameter be increased slightly in excess of that immediately behind it, and that the junction between the wheel and the axle be thoroughly well secured. The fixing of the wheel on the axle has a very considerable influence upon the strains. If the nave be short, and no keys be used in the connection, the tension must be proportionally great per square inch of surface of contact. Again, the "grinding" of the flanges of the wheels occasions a particular pressure on this part of the axle, and tends to shear it with a force inversely as the length of the bearing. This tendency to shear may be mitigated by rounding the exterior edges of the nave of the wheels. The fixing of wheels on axles of cast steel requires a much greater force than is necessary in the case of iron axles, so that a greater pressure being exerted, the bearings may be made relatively shorter. The proportion is as 0.22 to 0.36. There is no necessity to adduce examples that fracture of railway axles rarely or never occur at the centre, but always at or near the dangerous section. A report from Captain Tyler with reference to an accident that happened in September last, bears out this well-known fact. The axle of the tender broke almost exactly across this section, and the form of the axle was such that the diameter of the bearing was less than that of the dangerous section. The fracture occurred at the shoulder, or the point where the diameter alters. Had the diameter of the part in the wheel-bed been the same as that of the dangerous section the strength of the axle would have been increased, but it would have been further augmented, and possibly to a degree that might have prevented the accident, if it had been increased in the proportion we have described in that portion of our article relating to the relative diameters of the different sections of the axle. That the breaking of the axle in question was due to a radical defect in the form, and not to an inferior quality of material, was proved by the fact that Captain Tyler had the remaining length broken by actual experiment, when it was found to be of excellent quality. Since this accident, the North-Eastern Railway Company, upon whose line it took place, have modified the form of their axles. In the new and improved shape, the shoulder or sudden change in the diameter of the axle, which is a diminution exactly at the point where an increase should be made, has been altogether done away with, and the diameter of the bearing or wheel-bed made larger than that of the dangerous section. The breaking of the axle of an engine, tender, or carriage may be attended with contingencies so fatal and disastrous, that the determination of the proper and

strongest form is a question of the greatest importance. This can only be accurately ascertained by an analysis of the strains and a mathematical investigation into the conditions of the case, a subject to which we shall return at an early opportunity.

FOREIGN SCIENTIFIC NOTES.

From "Engineering."

THE GALVANOMETER BALANCE.

The last bulletin of the Société d'Encouragement pour l'Industrie Nationale contains the description and theory of a new galvanometer, invented by M. Bourbouze, lecturer at the Faculty of Science and at the School of Medicine in Paris. The following remarks extracted from the bulletin are sufficient to explain the arrangement and the advantages of this apparatus. In M. Bourbouze's galvanometer, which he calls "galvanometre balance," the magnetic needle is replaced by a magnetic bar oscillating inside the multiplier frame, the spires of which are horizontal. A current passing through the multiplier, deviates the magnetic bar in the same manner as the lever of a balance would be affected under the influence of an unequal load in one of the scales; and further, as in ordinary balances, the magnetic bar carries at the centre a needle which passes over a graduated sector, allowing thus a means of ascertaining the extent of the deviation.

The lower end of the needle has a screw thread cut upon it, and carries two small adjustable weights. A second rod, perpendicular to the first, also carries two similar weights arranged on each side of the axis of suspension. By moving these masses the magnetic bar will be placed horizontal; the influence of the earth being opposed by the moment of the weight of the lever at a sufficient distance of the axis of suspension. These weights also allow of a sufficient displacement being given to them, so as to vary the direction of the general resultant of the forces which act upon the system, and thus regulate the sensibility of the apparatus by making this direction pass as near as possible the axis of suspension.

When the south pole of the magnetic bar is directed exactly towards the north, the disposition of the masses allow of obtaining at will any one of three equilibriums, stable, unstable, or indifferent. The sensitiveness of the apparatus can also be made to vary in proportion to the nature of the experiment that has to be made.

The sensibility can be modified in another manner. By an arrangement similar to that adopted in hydrostatic balances, that is to say, by means of a rack and pinion, the balance, properly so called, may be raised or lowered. The multiplier remains fixed; the variation of the distance of the magnetic lever from the centre of the multiplier produces a modification corresponding with the sensibility of the apparatus.

We may state, in conclusion, that M. Lissajous has made an exceedingly favorable report on the galvanometer balance, which, he affirms, combines with a perfect sensibility an incontestable accuracy.

NAVIGABLE BALLOONS.

Our readers will remember the navigable balloon of M. Dupuy de Lome, who proposes carrying on his experiments, substituting for the motive power developed by hand, that of a suitable mechanical motor. Public attention has been lately called to this balloon by articles in different journals announcing that it was entirely spoilt on account of the deterioration of the varnish which had been employed. This varnish was composed, according to the journals, of a mixture of gelatine and glycerine.

M. Dupuy de Lome has given a formal denial to their assertions at a recent meeting at the Academy of Sciences. The varnish, already applied for fourteen months, is in a perfect condition, thanks to the precautions that have been taken. He stated that the composition consisted of three equal parts of gelatine, of glycerine, and of tannin, dissolved warm in twelve parts of pyroligneous acid, and that this composition had been employed from experiences obtained by M. Troost, professor of chemistry at the Normal School, from the recommendation of M. Dumas.

UTILIZATION OF THE MOVING POWER OF SEA WAVES.

The question, however delusive, of employing economically the moving power of sea waves, continues to occupy inventors.

We described some time ago the dynamometric apparatus proposed by M. Gusman, and which is intended to transform the rolling and pitching motions of a vessel into a useful moving power. Two new arrangements have recently been patented in France, which may be briefly described.

One of these arrangements, invented by M. Barreau, Jr., Civil Engineer, at Alexandria. is designated hy him a "Marine Motor," as using in a rational (?) manner, the force exerted by the sea waves as a motive power. He intends to raise the water of the sea above its level by the natural power of the waves, for which purpose a basin or reservoir of iron or masonry is to be constructed on the sea coast, and closed towards the sea by a sliding lock gate, the height of which is regulated according to the power of the waves. These meeting with the fixed obstacle, caused by the presence of the lock gates, rise along it, and fall over its crest into the reservoir. In order to facilitate the retaining of the sea water by the lock gate, the side walls of the reservoir, to the right and left of the gate, are widened, forming thus a kind of funnel. The water accumulates thus in the reservoir at a level somewhat higher than that of the sea. The reservoir is closed at the land side by a second movable lock gate, which permits the water of the reservoir to act upon a water wheel driving any machine. During the inactivity of this machine, the water wheel is to store up power, either by compressing air or by raising water in a reserve basin.

The second arrangement, proposed by M. Roche, lemonade seller at Nîmes, consists chiefly in using the rising and falling motion of the waves for the purpose of giving an alternate vertical movement to a floating cask, attached to the end of a long wooden lever, which turns round a fixed point on the shore, and which drives a pump for compressing of air in a reservoir. The inventor indicates a second arrangement, in which the cask is replaced by a float moving round a horizontal axis. The alternate motion of the float and its axle under the action of the waves, is transmitted to the large lever by two perpendicular cranks fastened upon the axle. Although the inventor himself qualifies these arrangements as rudimentary (very justly!) he states, nevertheless, that they have given him good results. In experiments made at Marseilles, with a compressed air reservoir of a capacity of 24 cubic ft., the gauge indicated at the end of 12 min. working, 3¼ atmospheres, after 16 min. it showed four atmospheres, and after 22 min., five atmospheres. The experiments were not carried further, as it was feared that the reservoir was not strong enough.

LAURIUM.

The quarrel which the Government of Greece began a couple of years ago with the Roux-Serpieri Company about some mining property at Laurium, near Athens, is still undecided, and threatens to become of political importance. It is, therefore, fortunate that an impartial report has just been published upon the merits of the question, by two Prussian mining engineers, Baron Dücker and Assessor Nasse, who, at the request of the Greek Government, have investigated the case. From this it appears that the Roux-Serpieri Company had a right to the old lead mines and their halvons, or heaps of refuse, but clearly not to any refuse which was derived from dressing and smelting operations, viz., tailings and slags. The Company, however, found it more advantageous to work the latter instead of the former, which they only needed to remelt at their lead works of Ergastiria. It appears that at some distance from the mines, principally at three places, called Camariza, Santirina, and Berseco, there are large Leaps of tailings and lead slags, intimately mixed, found in heaps of from 5 to 10 metres in height, and that their contents of metal are valued by the Prussian engineers at something like 25,000,000 francs, whilst the similar deposits near Ergastiria are nearly exhausted. The Greek Government is therefore quite right, and in accordance with a mining law of April 14, 1867, to levy a duty of 30 per cent. on the net profit of the company so far as it comes from the ecvolades, and an agreement would have been come to long ago if the Roux-Serpieri Company had not brought forward entirely ridiculous claims by asking 20,000,000 francs for their smelting works at Ergastiria.

HOT BLAST.

Professor Akerman, of the Polytechnic Institution of Stockholm, and Professor Peter Tunner, of the Mining School of Leoben, in Austria, have lately published their views on the influence of hot blast in the blast furnace. The former contends that the great increase of temperature, and conse-

quent economy of fuel, is chiefly attributable to the circumstance that the heat, which is carried by the blast into the furnace, as compared with that created by the combustion of the fuel, is introduced therein without increasing the volume of gases, as a greater bulk of expanded gases escaping at the furnace top will naturally carry a greater amount of heat with it. Seeing, however, that blast of only 350 to 450 deg. Fah. will cause an economy of 25 per cent. of fuel against cold blast, Tunner means that besides the actual quantity of heat which the blast carries with it, its favorable influence must be looked for in the fact that it facilitates a rapid and complete combustion of the fuel, forming carbonic acid only, which again is not so easily to be reduced into carbonic oxide as Akerman and Bell seem to take for granted. While Akerman is of opinion that for producing white forge pig, the temperature of the blast should not be raised over about 500 deg. Fah., it may be opposed to this, that in Styria white and mottled pig iron are constantly produced with hot blast of over 900 deg. Fah., when the burden is only fluxed with somewhat more lime, the pressure of the blast diminished, and the crucible widened to some extent.

The Wasseralfingen system of horizontal and elliptical heating pipes utilizes the heat of the stove better than vertical pipes, as the cold air during its passage through the heating stove comes in contact with pipes of ever increasing temperature until it goes to the blast furnace; the absorption of heat being much more perfect when the pipes have a proper width in their greater diameter, so that the blast gets time to take up heat from their inner surface, when the stove is sufficiently high and wide to allow of a perfect mixture and combination of the air and the heating gases. It is evident when the cold blast enters the heating apparatus at its coldest, and leaves it at its hottest part, that its temperature will be always somewhat less than that of the pipes which it passes; that it consequently is in a still fit state for taking up heat from the latter. As cast-iron pipes will limit the degree of temperature which is obtainable, through their own fusibility, the Siemens regenerative principle has been also applied for heating blast. The Cowper apparatus seems to be more liable to become choked than that of Whitwell, which requires cleaning only once every three months. The latter was lately materially improved by enlarging considerably its first compartment; a though its surface of contact was materially lessened, the temperature obtained was much greater, owing to the better combustion and the increased delay of the gases in the widened chamber. Though the regenerative system offers many advantages over the pipe system, it has not found much favor with Continental iron works, because it requires a large area, and is not so easily controlled and repaired as the latter.

The great Sardah Canal project, India, which has been under survey for nearly six years, and which received the sanction of Government some months back, has, it appears, again met with a check, as just after the works of construction had been fairly commenced, an order was issued from Simla to suspend operations and disperse the greater part of the engineering staff on other works. This imperial project, which was intended (at an estimated cost of three millions sterling) to irrigate the vast plains of Oudh, and which would have been the great hydraulic work of India, has for the present been suspended owing to the strong opposition offered to it by the native proprietors of the land, who state that such a canal would defertilize the ground by depositing silt and sand carried from the hills on their alluvial plains, and further that it would render the country unhealthy by producing fever and other malarious diseases. The advocates of the scheme deny all this, and state that the opposition of the Zemindars arises from their disinclination to any modern encroachments or improvements on their estates or amongst their ryots or tenants.

There is, no doubt, much truth on both sides, and now, after six years engaged over this project, a committee is to be appointed to decide whether the canal is really necessary at all, or whether irrigation is advantageous or otherwise in Oudh. So we shall have more prolonged deliberation, blue books, and reports, before any further active steps are taken, or the project is finally abandoned.

The "Gazette of India" publishes the resolution of the Government of India regarding the failure of the Saugor Barracks, and it states that "the failure of those buildings is the most signal instance of waste of public money which has taken place of late years." The Saugor Barracks, which have

cost the Government £166,000, have been for some time considered unsafe, and a committee which was appointed to examine the buildings and investigate the whole question, has recommended that the barracks should be altogether abandoned.

Captain Faber, R. E., is pronounced by the Government unfit for the duties of executive engineer, and has been returned to military duty. Mr. Campbell has been reduced from the first to second grade of superintending engineer, as a mark of the displeasure of Government; and Colonel Collard, the chief engineer, is also reduced a step; while, on the other hand, Mr. Fitzjames C. E., receives the approbation of the Government for the determined manner in which, despite the snubs of his superior, he brought the unsound state of the buildings to the notice of the Government. Two other military engineers were also connected with the construction of the barracks; but as one is dead and the other has retired, they escaped blame.

The "Pioneer," in commenting on the above orders of Government, writes very fairly and truthfully in the following paragraph:

"The real and chief blame of the failure of the Saugor Barracks attaches to such members of Government, and especially to such secretaries to Government in the Public Works Department, as are influential in maintaining the system by which the officers responsible for a great work are changed half-a-dozen times during its progress, as if to secure that no single one shall have any pride in its success, or any serious liability on its inevitable failure. The system of removing officers from great works on their departmental promotion is simply imbecile, and those who maintain it are culpable—far more so than those who suffer the censure dispensed with such mock-virtuous austerity."

Mr. G. L. Molesworth, C. E., the new consulting engineer to Government, has issued a very able report on the present state of progress—whether as regards actual work or survey—of the State Railways of India, which has been well spoken of by the press of this country, as he has clearly and lucidly laid before the public a true description of the work done, and being done, on our new railways, a course which is unusual in a country where a haze of official obscurity usually overhangs all works undertaken by the Public Works Department, and where the public are in a great measure left without information.

A little more than a year's experience of India appears to have shown Mr. Molesworth how difficult it is to make progress in the face of the barriers of control and routine which are for ever arising up before and obstructing the way of engineers, for he vigorously breaks a lance with "the Baboo" (the guardian angel of red-tape); but a little longer experience will show him the utter fruitlessness of resisting the all-powerful and real Juggernaut of India (moving along with a slow and lumbering pace and crushing under its leaden wheels every aspiration towards a better state of things), "Baboo-dum."

Much alarm has been lately felt at Madras, as it was feared that the "bund" or embankment of the Red Hill tank, which supplies that city with water, was in a dangerous state, as serious leaks were said to have been discovered. Great efforts were made to reduce the pressure on the bank by lowering the depth of water in the tank, which were fortunately successful. and it is now stated that all danger has passed away.

REPORTS OF ENGINEERS' SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—A regular meeting of this Society was held at its rooms in New York January 8th. A paper by Charles B. Richards, M. E., of Hartford, Conn., recording "Experiments on the resistance of stones to crushing," was read.

The specimens were old and dry samples, well selected, of various American building stones, worked into 1 in. and 1½ in. cubes, with flat and smooth faces.

The testing machine used was built, after a long experience, with two smaller and similar machines. It is arranged to weigh the strains upon a sensitive platform scale of 50 tons capacity, and is well adapted to quickly give accurate results.

The specimens were crushed between the plane faces of two hardened steel hemispheres, the curved portions of which were seated in corresponding cavities of steel blocks, fixed in the machine. Single thicknesses of "lace' leather were interposed between the stones and metal surfaces, thus the pressure was uniformly distributed; it was in all cases applied to the faces of the cubes parallel to the natural bed of the stone, and carefully increased to rupture by pouring shot into the hollow weight by which the strain was caused.

Tables were presented, giving the minimum, mean, and maximum resistance to crushing per square inch of the specimens tested.

Sixteen specimens of granite from six quarries, gave from 8,620 to 15,622 lbs. minimum, 9,838 to 18,778 lbs. maximum strength; fourteen specimens of sandstone from 3 quarries gave from 5,806

lbs. minimum, and 8,956 to 10,928 lbs. maximum strength; and ten specimens of *white marble* from three quarries, gave from 3,905 to 12,917 minimum, and 5,976 and 13,972 lbs. maximum strength, each being 1 in. cubes.

The specimens failed by breaking up into slender prisms and pyramids with axes normal to the pressure.

A brief paper by F. Collingwood, C. E., of New York, upon "Rock Drilling," was also read.

In it was stated that a percussive steam drill, with 3 in. cylinder and 6 in. stroke, making 300 to 375 strokes per minute, would drill in the coarse gneiss rock, common on New York Island, 1⅝ in. holes 3 in., 1¾ in. holes 4½ in., and 1 in. holes 5 in. per minute.

Joseph P. Davis, C. E., of Boston, Mass., compared the late Chicago and Boston fires, and suggested a question for discussion, and one on which information is much needed—namely: Fires and their management. The best appliances and methods for putting them out.

Upon motion of M. N. Forney, M. E., of New York, a committee, consisting of Messrs. Ashbel Welch, of Lambertville, N. J.; John Griffin, of Phœnixville, Pa.; Max. Hjortzberg, of Chicago, Ill., and two others to be named by the chairman, were appointed to make an investigation by means of a circular of inquiry sent to each member of the Society, and by such other methods as the committee may choose to adopt, to determine the following points:

1. The best form for standard rail sections for the railroads of this country.
2. The proportion which the weight of rails should bear to the maximum load carried on a single pair of wheels of locomotives or cars.
3. The best method of manufacturing and testing rails.
4. The endurance, or, as it is called, the "life" of rails.
5. The causes of the breaking of rails while in use, and the most effective way of preventing it.

The committee to report the results of their investigations at the next Annual Convention of the Society.

SCIENTIFIC AND MECHANICAL SOCIETY OF MANCHESTER.—An ordinary meeting of this Society was held on Wednesday, the 8th inst., at the Trevelyan Hotel, Manchester, Mr. W. H. Harman, C. E., M. I. M. E., Vice-President, in the chair, who, in opening the proceedings, alluded in fitting terms to the death of the late Professor Rankine, which loss we all so deeply deplore.

The following is a list of the subjects on which the Council invite communications:—"The Nominal H. P. of Steam Engines;" "The Friction of Steam Engines, based if possible upon experimental research;" "Chimneys—Sectional Area, Altitude, Draught, etc.;" "The Relative Strength of Structures, with Punched and Drilled Rivet Holes;" "The Introduction of Steel in Structures as a Substitute for Wrought Iron;" "Pure Science;" "Chemistry;" "Electricity;" "Geology," and others.

After the election of six new members, and the proposal for election of five others, Mr. J. Shepherd, M. E. and Vice-President, read his paper "On Sectional Boilers," with special reference to the Patent Cop-tube Boiler.

The paper was so full of interest, illustrated by drawings and a small model, that we reserve the same for our next issue in order to print it *in extenso*, and in the meanwhile we will procure a sketch of the same, so as to make the description as clear as possible.

At the next meeting a paper will be read "On the Effect of Sudden Alteration of Form on the Strength of Materials.'

IRON AND STEEL NOTES.

THE SCOTCH IRON TRADE OF 1872.—The year just closed was the most remarkable which the history of the iron trade has probably seen. The phenomena, whether as regards price, stocks, demand and production, and the misunderstandings and disputes of masters and workmen, are alike novel and unprecedented, and have, moreover, attained such an appearance of permanence as to justify the deepest possible interest as to the future.

The statistics of the Scotch iron trade during the year, now in course of preparation by the Committee of the Glasgow Association of Iron Merchants and Brokers, will shortly disclose the results of the annual transactions, and their comparison with the previous years; but the subject is sufficiently important to induce us to anticipate the official statement.

The following is the comparative production of Scotch pig iron, as at the 25th of December, the last three years:—

Production—	1872. Tons.	1871. Tons.	1870. Tons.
From return of makers	1,100,000	1,160,000	1,206,000

During all these three years the production of pig iron has been steadily and annually diminishing in Scotland; and this diminution has been going on in the face not only of greatly increasing demand, but of constantly rising prices, and of prices in their culmination this year quite unprecedented in amount, and destructively reactive on all the springs of industry and manufacture by their very exorbitance. The average price of Scotch pig iron in 1870 was 54s. 4d. per ton, when the production was 1,206,000 tons; in 1871 the average price was 58s. 11d., and yet the production sank to 1,160,000 tons; and this year the average price has been 101s. 6d., when the productions have been only 1,100,000 tons! There is, certainly, no branch of production in this country that has ever exhibited such results as these; and we may be prepared to find some cause counteracting and overruling the natural laws that ordinarily govern the relations of demand and supply and of price and production, which cause may either be—since we cannot give our speculation at this point too free a range—(1) some exhaustion of the physical materials of production, coal and ironstone; or (2) some increasing difficulty of bringing these essential physical materials into practical co-operative conjunction; or (3 some chronic misunderstanding betwixt iron and coal masters and their work people, by which they have been rendered quite unable to command the labor necessary to supply the demand for their products under the most favorable conditions otherwise ever known; or (4) some inherent stupidity on the part of the working miners and their families alone, and the laboring class generally, that

has rendered all the best and most profitable intentions of the masters fruitless; or (5), which is the least conceivable hypothesis of all, that there is something wrong in the mere marketing of pig iron, whereby the profits of increasing and exorbitant prices go wholly into the pockets of merchants and speculators, and consequently exercise no economic action over iron and coal owners at all. With apparently the most vigorous intentions to meet both foreign and domestic demand, the Scotch ironmasters have altogether failed to do it. At the end of last year the number of furnaces reported as "existing and nearly ready" was 154. At the end of 1870 they were even 160. But the average number of furnaces actually in blast, which had been 130 in 1870, sank to 127 in 1871, and during the present year have further fallen to 123. But in striking an average for a year one must be cautious, for the furnaces in blast this year have been diminished by a dozen or two within the last few days. What can all this mean under the growing demand and high price given for "Scotch pig?" Has a great blight fallen suddenly on the once famous mining enterprise and energy of Scotland? Have the coal and ironmasters and Mr. Alex. M'Donald and the working miners in their furious struggles against each other for years fallen into a trance of mutual masculation, and become all unconscious that the sceptre is departing, if it has not already quite departed from them? The great world, in its demand for iron, will certainly not be long stopped in its progress by a market which discovers no elasticity, and shrinks year after year in dimensions when it has every motive and inducement to enlarge.

COMPOSITION OF CRYSTALLIZED CAST IRON.—C. Rammelsberg has lately in the "Ber. d. Deutsch. Chem. Ges., 1872, p. 430," published the results of his analyses of two specimens of crystallized cast iron, which are as follows:

(*a.*) Grey cast iron crystallized in regular octahedrons, being found in the centre of a broken roll employed for rail rolling at the Henrichhuette at Hattingen; its specific gravity was found to be 7.255, and it contained—

Metallic iron	95.225
Carbon graphite 1.121 } " combined 1.963 }	3.084
Silicon	1.537
Sulphur	0.113
Phosphorus	0.041
	100 000

(*b.*) White radially crystallized cast iron from Freisenburger Furnace (Neuschottland) having a specific gravity of 7.617.

Carbon	2.820
Silicon	0.334
Phosphorus	0.086
Sulphur	0.000
Metallic Iron	96.760
	100.000

The carbon in this case was all in a state of combination, excepting a trace of graphite, but the author remarks that graphite is not always absent in white cast iron, as in the speigeleisen from Madgesprung he found 16.5, and from Lohhuette nearly 28 per cent. of the entire carbon present to be in the graphitic form.

LAKE SUPERIOR ORE AND IRON IN 1872.—The following is a statement in gross tons of the production of ore and pig iron in the Lake Superior district from 1856 to 1872, inclusive, together with the aggregate value:

Year.	Iron Ore.	Pig Iron.	Ore and pig iron.	Value.
1856	7,000	....	7,000	$28,000
1857	21,000	....	21,000	60,000
1858	31,035	1,629	32,661	249,202
1859	65,679	7,258	72,937	575,529
1860	116,908	5.660	122,658	736,496
1861	45.430	7,970	53,400	419,501
1862	115.721	8,590	124,311	984,977
1863	185,257	9,813	195,070	1,416,935
1864	235,123	13,832	248,955	1,867,215
1865	196,256	12,283	207,539	1,590,430
1866	296.972	18,437	315,309	2,405,960
1867	466,076	30,911	496,987	3,475,820
1868	507,813	38,246	546,059	3,992,413
1869	633,238	39,003	672,241	4,968,435
1870	856,471	49,298	904,319	6,300,170
1871	813,379	51,225	864,604	6,115,895
1872 ...	952,055	63,195	1,015,250	9,188,055
Total..	5,537,373	357,880	5,903,803	44,373,833

—*Marquette Mining Journal.*

ANALYSIS OF WHITE PIG IRON AND ITS SLAG.—From the "Berg und Huettenmännisches Jahrbuch der K. H. Bergakademien Zu Przibram und Leoben, Prag., 1872," we extract the following analyses of the white pig iron and slag produced along with it from the Neuberg blast furnaces. The analyses are by Von Eschka, v. Lill and Modes.

White pig iron—

Metallic iron	94.300
Carbon (combined)	3.123
Silicon	0.616
Phosphorus	0 036
Sulphur	0 045
Manganese	1.820
Copper	0.155
	100.095

Blast furnace slag produced along with the above—

Silica	43.70
Alumina	10.40
Protoxide of iron	0.13
" manganese	5.10
Lime	23.54
Magnesia	13.17
Potash and soda	2 22
Sulphide of lime	1.24
Phosphate of lime	0.078
	99.578

The ratio of the oxygen in the silica to that of the bases as shown in the above analysis is as 23.31 to 18.40, and the comparison of the two analyses is interesting as showing the great proportion of the manganese which is carried into the slag when white iron is produced, as compared with the much lesser percentage reduced into the pig iron.—*Journal of Iron and Steel Institute.*

PUDDLING BY THE FURNACE GASES.—In the charcoal iron furnaces in Carinthia, in Austria, the puddling has for some time back been carried on without other fuel than the gas from the blast furnaces, whereby it is stated that an economy of between £3 and £3 10s. per ton of bar has been secured. In this direction also the "Bulletin de Comitè des Forges," reports in favor of a new process by MM. Combescot and De Langlade, who employ the gases in a kind of regenerative Siemens furnace, which enables the temperature, pressure of the gases, and the duration of the flame to be perfectly regulated.

RAILWAY NOTES.

AMERICAN LOCOMOTIVES IN RUSSIA.—The "Russian News" reports the experiments made between the St. Petersburg and Laubane, November 25, with a Baldwin locomotive made to burn anthracite coal. With a train of ten cars it passed over the heaviest grades at the rate of 60 versts (10 miles an hour, and burned in running 130 versts (.86 miles) 62 poods (2,232 lbs.) of anthracite. These engines, it is believed, will be of great service in the south of Russia, where there are unworked mines of anthracite and very little wood, but where heretofore wood has been burned. "La Bourse," of St. Petersburg, also reports the trial, and describes the construction as follows: "The frame is solid instead of being of plates, the construction of the cylinders, the manner in which they are adapted to the machine, and the mechanism of all the details which enter into the construction of a locomotive, excel anything of the kind ever seen. But the most striking feature is the immense fire-box, about 9 ft. long, which forms the essential part of the system of heating with anthracite. Grates formed of several ranges of tubes, one above the other, extend from front to rear in the furnaces. These tubes communicating with the water spaces, the water circulates in them constantly, so that the interior walls are protected against the consequences of the intense heat produced by the combustion of anthracite. * * * The engine worked wonderfully well at the time, and it was noticed that there was no heating of the journals, such as is common in all new locomotives."

RAILROAD EXTENSION IN 1872.—There is some disappointment with the work of railroad extension for the past year. We have done less than was expected. We have built fewer new roads than in the previous year. We can show an increase of but 7,613 miles, against 7,878 miles of new roads in 1871; 7,433 in 1870. The whole length of railroad is now 70,178 miles; while 43,000 miles more are in various stages of incipiency, and will make our net work of railroads, when finished, 113,000 miles.

The growth of the network of iron roads in this country was very backward till the gold discoveries of 1848. At the close of that year we had less than 6,000 miles of railroad, of which 1,276 were in New England, 4,000 miles in the Middle and Southern States and less than 700 miles in the Great West. When the troubles of 1860 began, the network of railways had increased five-fold. The West rn States had 11,000 miles, the Southern States over 9,000, the Middle States nearly 7,000, and New England 3,600. These 30,000 miles had cost us 1,070 millions of dollars, more than one-tenth of which, perhaps, was foreign capital. The war did not stop our railroad building, as was feared. The work was only checked. In the second year of the war we had added nearly 2,000 miles to our railroad network, and had laid out 100 millions of dollars upon it, besides the vast cost of the war itself. At the close of 1865, the year of peace, or railroads had 35,000 miles, and now they have a length of nearly twice as much, or 70,178 miles. Since the war, then, we have built new railroads of 35,000 miles long. This is more than has been built in the whole of Europe in the same time. Had we no more than these 35,000 miles that have thus been made since the war, we should have a larger mileage of railroad than Germany, Austria, France and Russia, with their 175 millions of people. This will be seen from the following tables showing the railroad developments of these and other countries of Europe compared with that of the United States:

Railroads of the United States and of certain countries in Europe.

	Railroad miles.	Population.	Inhabitants per sq. mile.	Sq. mile to railroad mile
United States	70,178	38,555,983	14	43
Germany	12,207	40,111,265	189	17
Austria	5,865	35,943,592	158	40
France	10,333	36,469,855	151	19
Russia in Europe	7,044	71,207,794	36	284
Great Britain	15,537	31,817,108	265	8
Belgium	1,901	4,839,094	430	9
Netherlands	886	3,858,495	236	15
Switzerland	820	2,669,095	175	18
Italy	3,667	26,273,776	225	29
Denmark	420	1,784,741	111	34
Spain	3,401	16,301,850	90	54
Portugal	453	3,987,897	99	81
Sweden and Norway	1,049	5,860,122	19	180
Greece	100	1,352,508	71	199

—*Railway Monitor.*

ENGINEERING STRUCTURES.

THE DEEPEST WELL IN THE WORLD.—At about twenty miles from Berlin is situated the village of Sperenberg, noted for the deepest well that has ever been sunk. Owing to the presence of gypsum in the locality, which is at a moderate distance from the capital, it occurred to the Government authorities in charge of the mines to attempt to obtain a supply of rock salt. With this end in view the sinking of a shaft, or well 16 ft. in diameter, was commenced some five years ago, and at a depth of 280 ft. the salt was reached. The boring was continued to a further depth of 960 ft., the diameter of this bore being reduced to about 13 in. The operations were subsequently prosecuted by the aid of steam until a depth of 4,194 ft. was attained. At this point the boring was discontinued, the borer or bit being still in the salt deposit, which thus exhibits the enormous thickness of 3,907 ft. The boring would have been continued in order to discover what description of deposit lay under the salt, but for the mechanical difficulties connected with the further prosecution of the operations. During the progress of this interesting work repeated and careful observations were made of the temperature at various depths. The results confirm very closely those which have been already arrived at under similar circumstances.

COST OF TUNNELS.—The "Times," in an article on the English Channel Tunnel, gives the following list of first-class tunnels, with their costs:—

The Mount Cenis Tunnel, £7,450,400—$37,000,000.

The Kilsby Tunnel in England, estimated at £90,000, cost at last £350,000—$1,750,000, owing to vast quantities of water from unexpected sources, drowning at the works, and requiring 13 steam engines, 200 horses, and 1,250 men, working day and night for eight months. From the quicksand alone 10,000 gallons of water per minute were pumped. Total expense of tunnel £145 per yard for 2,400 yards.

Were the English Channel to cost at this rate, its 22 miles would cost £5,646,620—$28,000,000.

The Saltwood Tunnel cost £118 per yard.

The Bletchingly Tunnel, £72 per yard.

Taking these figures for 22 miles would make the English Channel Tunnel cost either £4,568,960, or £2,787,840; that is to say, anywhere between $23,000,000 and $14,000,000.

The Terre Noire Tunnel in France, on the Paris Marseilles road, cost £30 per yard.

The Batignoltes, near Paris, £95 per yard.

The Braine le Compte in Belgium, £41½ per yard.

The Liege and Verviers Tunnels, £45 per yard

The Hauenstein, between Berne and Basle, a very difficult work, cost £80 per yard.

The Hoosac has thus far cost £180 per yard.

The Moorhouse, in New Zealand, driven through lava, tufa, and dykes of phonolite, £68¾ per yard.

A TUNNEL at Cairo is proposed to pass under the Mississippi, and, perhaps, by a branch, the Ohio also, and so connect the railroads of Illinois with those south of the Ohio and west of the Mississippi. There are at present but two railroads completed to Cairo north of the Ohio, and none south of it or west of the Mississippi; but the Cairo and Fulton is to be rebuilt to Bird's Point (on the Missouri shore west of Cairo), we believe, and an extension of the Mississippi Central from Jackson, Tenn., to the Ohio, is under contract, and as both streams are wide at Cairo, not easily bridged for want of banks and the great number of vessels passing, and not always easily ferried, a tunnel would be a great help to traffic, whether or no it would be profitable. The work doubtless is practicable, but costly, and if completed it may do much to establish the importance of Cairo, as railroads might be diverted from crossings at other points on either river in order to secure the safe one at Cairo.

A company to construct such a tunnel has been formed, with capital stock amounting to ten millions, and has applied to Congress for a charter. As a tunnel, unlike a bridge, cannot possibly interfere with navigation, it is not probable that any one will object to its construction. Officers of the Pennsylvania Company and of the Cairo and Vincennes Railroad Company are named among the supporters of the project, which would be, we should say, much more costly than the proposed Detroit Tunnel, and, of course, for some years at least, with very much less traffic to support it.—*R. R. Gazette.*

ORDNANCE AND NAVAL.

STATE OF THE BRITISH NAVY.—Our iron-clad navy is numerically strong, but we fear intrinsically weak. The only new armor-plated ships that are nearly ready for sea service are the Triumph and Devastation, while five wooden ships, which were plated when the La Gloire panic was at its height, have been worn out, and no attempt has been made either to replace or repair them, viz., Royal Oak, Prince Consort, Ocean, Caledonia, and Jealous. Again, six others, Black Prince, Hector, Defence, Resistance, Penelope, and Lord Clyde, must have new boilers before anything like three months' real work could be got out of them, and if all the resources of our dock-yards were to be made available the work could not be accomplished before the beginning of January, 1874, by which time we shall have on our hands four others, viz., Royal Alfred, Lord Warden, Northumberland and Agincourt; and perhaps the Favorite will also be in an equally bad state. There is not a single frigate ready for the pennant, and the Active is the only corvette which could reasonably be commissioned at once. Sir Alexander Milne will have no sinecure; but the country must be satisfied as to the condition of its navy. We have no desire to be alarmists; but the simple facts which we now place before the public will, if attended to at once, possibly save us from much trouble.—*Army and Navy Gazette.*

THE RUSSIAN NAVY.—The St. Petersburg correspondent of the London "Morning Post," under date of Dec. 24, 1872, says: "It would seem, to judge by the gigantic forges and mechanical works of every kind which are now being established in Cronstadt, that even the immense naval preparations of the present year have not satisfied Russia, and that she is meditating new and prodigious efforts for 1873. Yet, granting that the

quality of her vessels is what it should be, their number and armament might surely satisfy her. The Baltic fleet alone numbers on its lists 27 powerful iron-clads, including those still building, of the following calibre: The Sevastopol, 26 guns; the Petropavel and Pervenetz, 24; the Kreml, 18; the Ne Tron Menya, 17; the Prince Pojarski, Alexander Nevski and General-Admiral, 8; the Lazareff and Greig, 6; the Tchitchagoff, Spiridoff, Minin, Kreiser, Tcharodaika and Rusalka, 4; the Ouragan, Typhon, Smertch, Strailetz, Edinorog, Bronenosetz, Latnik, Lava, Peroun, Veshtchoun and Koldoun, 2. The total strength of the Russian navy, as officially stated (which does not necessarily imply that the statement is correct), stands as follows: Baltic fleet, 136 vessels; Black Sea fleet, 31; flotilla on the Caspian, 29; flotilla on the Sea of Aral, 5; Siberian squadron, 32—the whole forming an aggregate of 233 vessels of war, manned by 2,850 officers and 20,890 men.

TOTAL ARRIVALS FOR THE YEAR 1872.—During the year ending December 31, 1872, there arrived at this port, from foreign ports, a total of 5,619 vessels, as follows:

	Steamers.	Ships.	Barks.	Brigs.	Schooners.	Total.
January...	52	43	123	88	78	384
February..	58	24	58	92	84	313
March	59	26	91	102	77	355
April.....	75	54	225	171	141	666
May.....	85	56	219	153	187	700
June	85	34	168	149	148	584
July.....	86	30	128	112	141	497
August ...	79	42	158	152	112	543
September	91	40	127	109	86	453
October ..	92	38	132	105	93	461
November.	75	19	105	79	58	336
December	73	25	84	82	63	327
Total...	910	431	1,618	1,395	1,265	5,619

During the same period there arrived from Southern coasting ports, 3,016 schooners, as follows:

January	239
February	163
March	161
April	327
May	361
June	277
July	278
August	257
September	316
October	271
November	186
December	180
Total	3,016

THE CLYDE SHIPBUILDING TRADE IN 1872.—It appears that 1872 has been the most prosperous year in shipbuilding yet experienced on the Clyde. Although the number of vessels launched has not been quite up to each of the last few years, the tonnage exceeds 1871 by 28,000 tons; and 1870, by 34,200 tons. The increase of last year has been larger than any yearly increase for many years past, and has been entirely in the class of screw steamers. The year's tonnage of screw steam vessels is 40,800 tons above 1871, 67,500 tons above 1870, 73,000 tons above 1869, and 77,500 tons above 1868. But while the screw vessels have so enormously increased, all the other classes seem on the decline. In paddle-steamers the year only shows 6,200 tons, against 10,900 in 1871, 10,150 tons in 1870, 8,300 tons in 1869, and 6,300 in 1868. In yacht building there has been a good trade, chiefly in screw steam vessels. Hopper barges and dredges also show a falling off as compared with 1871, but exceed the two preceding years. In iron sailing vessels there is a slight improvement over the preceding year of 2,200 tons, but, as compared with 1870, the decrease is 20,000 tons; and with 1869, the decrease is 51,000 tons. Composite and wooden ships are equally low.

A NEW iron-clad man-of-war was launched at Copenhagen on the 12th ult. It is a casemated steamer of 2,500 horse-power, 230 ft. in length, 47 ft. wide, and gauging 15½ ft. Denmark possesses now three iron-clad frigates with respectively 16, 18 and 24 cannon, and four floating iron-clad batteries, with respectively, 2, 3 and 4 cannon.

BOOK NOTICES.

ELECTROSTATICS AND MAGNETISM. Reprint of Papers on Electrostatics and Magnetism. By Sir W. THOMSON, D. C. L., LL. D., F. R. S., F. R. S. E. London, 1872. For sale by Van Nostrand.

To obtain any adequate idea of the present state of electro-magnetic science we must study these papers of Sir W. Thomson's. It is true that a great deal of admirable work has been done, chiefly by the Germans, both in analytical calculation and in experimental researches, by methods which are independent of, or at least different from, those developed in these papers, and it is the glory of true science that all legitimate methods must lead to the same final results. But if we are to count the gain to science by the number and value of the ideas developed in the course of the inquiry, which preserve the results of former thought in a form capable of being employed in future investigation, we must place Sir W. Thomson's contributions to electro-magnetic science on the very highest level. —*Nature.*

ANNUAL REPORT OF THE CHIEF SIGNAL OFFICER TO THE SECRETARY OF WAR FOR THE YEAR 1872. Washington: Government Printing Office.

This is an important addition to meteorological science. It would be difficult to overrate it. The summary of the observations at the several signal stations is of itself of decided value. Not the slightest doubt can attach to the accuracy of the observations made under such supervision as the present Signal Service insures. Heretofore we have been obliged to accept such data as we could gather from local papers and agricultural reports, which were compiled chiefly, especially in the Western States, from the rough guesses of some volunteer reporter. Such a theory will alone account for the

statements upon which we formerly relied for our knowledge of the climate of districts at a distance from the sea coast.

Aside from the interest with which the physicist will read General Myer's report, the engineer will regard it with a practical eye. The rainfall of different months, the range of temperature, and even the direction and force of the wind are important data in forming estimate of cost of engineering operations of all kinds.

The general reader will feel a special interest in the detailed description of the stately march of some of the great storms of the past year. The maps alone will tell the story quite completely.

Nothing is more obvious than that the Signal Service has by judicious management won the public confidence. The daily reports are now indispensable, at least in the eastern part of the United States. The service may be regarded as a fixed fact, and we may doubtless confidently expect yearly additions to the knowledge of the meteorology of our broad country.

Such reports as the present will be regarded by scientists the world over, as of the highest value.

THE ADMINISTRATION OF JUSTICE UNDER MILITARY AND MARTIAL LAW. By CHARLES M. CLODE. London: John Murray.

The author of this new work has labored faithfully to invest the study of the military code with a new interest by clothing the otherwise dry details with numerous scraps of military and constitutional history.

The subjects of the several chapters are: Introduction; The Military Code Prior to the Mutiny Act; The Mutiny Act; The Military Code After the Mutiny Act; The Initiation of Legal Proceedings by the Arrest of the Offender; The Arraignment, Trial, and Sentence of the Prisoner; The Confirmation and Execution of a Court-Martial Sentence; Martial Law; Courts of Inquiry.

The volume is a handsome royal octavo of 370 pages. For sale by Van Nostrand.

THE EARTH A GREAT MAGNET. By ALFRED MARSHALL MAYER, PH. D. New Haven, 1873. For sale by D. Van Nostrand.

We congratulate scientific readers that so valuable a summary of the laws of terrestrial magnetism is presented in so compact and cheap a form. Although prepared for a popular lecture, nothing of scientific accuracy is sacrificed, and the reader is insured the possession of the most advanced science by the standing of the author among the philosophers of the day.

JOHNSON'S NATURAL PHILOSOPHY AND KEY TO PHILOSOPHICAL CHARTS. By FRANK G. JOHNSON, A. M., M. D. New York: J. W. Schermerhorn & Co.

This work is adapted to the use of our common schools. The abundance and general excellence of the illustrations will serve to supply deficiencies in the way of apparatus. The suggestions afforded to teachers in drawing diagrams upon the blackboard are of the highest value; for every one of the five hundred cuts could be copied upon the blackboard by any teacher possessing a moderate degree of skill in using the crayon; the broad white lines on a black ground suggest at once a transfer to the blackboard. The exercise of copying these illustrations would be of the highest value to the student, as he would accomplish two purposes.

The errors of the book are chiefly of the kind incident to a first edition. The author treats with proper fulness each of the topics belonging to general physics, and adds a compact outline of astronomy in the concluding chapter.

A PRACTICAL TREATISE ON PURE FERTILIZERS, and the Chemical Conversion of Rock Guanos, Marlstones, Coprolites, and the Crude Phosphates of Lime and Alumina generally, into various valuable Products. By CAMPBELL MORFIT, M.D., F.C.S., formerly Professor of Applied Chemistry in the University of Maryland. With twenty-eight Illustrative Plates, or Construction Plans, drawn to Scale Measurements. London: Trübner & Co., 60 Paternoster Row. New York: D. Van Nostrand.

As is well known, there are no fertilizers to compare with phosphates. Their virtue consists in phosphorus united with oxygen as phosphoric acid which acid is found combined with lime in bones, and with lime, alumina and oxide of iron in what are known as rock guanos or mineral phosphates and coprolites.

It would be of little use to strew coprolites or pieces of rock guano over a field. They would lie there hard and inactive as pebbles. Mineral phosphates are therefore crushed to powder; but not even then are they fit for manure. They would indeed fertilize slowly, but far too slowly for the farmer. It is therefore necessary to make the phosphate of lime soluble; and thus it is accomplished.

With the powdered rock guano is mixed sulphuric acid, otherwise oil of vitriol, and the result is that two-thirds of the lime with which the phosphoric acid is united is converted into sulphate of lime, otherwise gypsum, and the third remaining with the phosphoric acid is what is called superphosphate, or soluble phosphate of lime.

By this operation, however, we do not get superphosphate in isolation. It is, in the first place, mixed up with the two-thirds of the lime which by the action of the sulphuric acid has been converted into gypsum. Moreover, no rock guano or coprolites consist entirely of phosphate of lime, but contain more or less chalk, silica, magnesia, oxides and phosphates of aluminium and iron, fluoride of calcium, silicate of lime, etc. The sulphuric acid does not affect the silica, but converts the chalk into gypsum. A similar action takes place with the silicate of lime and fluoride of calcium. As for the phosphates of aluminium and iron, they are of little assistance to vegetation, and may be regarded, like the silica and sulphate of lime, as so much dead weight.

Not unfrequently analyses of rock guanos are dishonestly set forth with the phosphoric acid as a separate item, and the lime, alumina, and iron run together as if of indifferent and equal values; but it is of the first importance to know precisely what are the associates of the acid. If the acid is locked up to a large extent with alumina and iron, it is so far ineffective. What the agriculturist ought to know, if he would have value for his money, is not how much phosphoric acid there is in the rock guano, but how much of the said acid there is in combination with lime. The superphosphate

commonly sold contains from 10 to 30 per cent. of soluble phosphate of lime. The remainder, of 90 to 70 per cent., is composed of sand, gypsum, phosphates of aluminium and iron, moisture, etc. Whoever buys a ton of superphosphate, as manufactured by the ordinary process, takes therein from 14 cwt. to 18 cwt. of rubbish, and sometimes a still heavier proportion when phosphates of aluminium and iron are palmed off as equivalent to phosphate of lime.

So much premised, we shall more readily appreciate the advantages of a process invented by Dr. Campbell Morfit for producing pure precipitated phosphate of lime. The rock guano is reduced to powder, placed in a vat, and a proper quantity of hydrochloric (otherwise muriatic) acid added thereto—which, by the way, is a very much cheaper acid than sulphuric. A current of steam is then blown through the mixture from the bottom of the vat, by means of which the contents are perfectly intermingled and the action of the acid facilitated. The result of this operation is that the mass of the rock guano, with the exception of the silica and fluorides, is brought into solution. The insoluble residue is thrown away, being valueless. Thus, one clear advantage is secured; for, as we have seen, by the usual method of superphosphating, the worthless ingredients are retained to burden and degrade the manure. The solution thus formed retains:—

All the phosphate of lime, All the phosphate of aluminium, All the phosphate of iron,	As phosphates (unaltered) in hydrochloric acid solution.
All the chalk or carbonate of lime,	Converted into chloride of calcium.

The next business is to get out of the solution the phosphate of lime in a solid form.

To do so by ordinary methods would be practically impossible. For, suppose we neutralize the acid which holds the phosphates of lime, iron, and aluminium in solution with chalk, we should precipitate all three phosphates in a common pulpy mass, and lose the whole of the acid in chloride of calcium.

Here comes Dr. Morfit's triumph. Readily and easily he precipitates the phosphate of lime *alone*, and yet does not sacrifice the acid. To the solution is added an adequate portion of the very impurities from which it is desired to deliver the phosphate of lime, namely, the oxides and phosphates of aluminium and iron. These elements then take the place of the phosphate of lime in the solution, and the desired phosphate of lime is thrown down as a pure white powder, consisting of a mixture of tri- and di-phosphate of lime.

Having thus isolated the phosphate of lime in a state of singularly fine division, we have in it a most potent fertilizer. No form of phosphate in Nature can be compared with it. What is known as superphosphate, if it maintained its ideal solubility, would probably be washed away by rain ere it had rendered its expected service; but its tendency to "go back," even in the bags used for its storage, is well known to the trade, and it is reasonably conjectured that nearly all superphosphate relapses into insoluble tri-phosphate when spread on the soil, and is decomposed gradually under the action of carbonic acid and vegetable life.

But whoever *will* have superphosphate need only stir into Morfit's pure precipitated phosphate a bare equivalent of dilute sulphuric acid, and leave it to dry. Being free from chalk, no acid will be lost thereon, and the formation of gypsum will be limited to two of the three atoms of calcium on which phosphoric acid is based.

The "mother liquor" out of which the phosphate of lime is deposited consists, of course, of phosphates of aluminium and iron in muriatic acid. The liquor is a counterpart, but in a much stronger condition, of the acid solution of Alta Vela guano, which is used for purifying sewage, and without the cost of special preparation. If the phosphates of aluminium and iron are wanted in a solid form, they may be precipitated by lime; and of course they are then available for the precipitation of fresh batches of phosphate of lime.

Valuable as Dr. Morfit's process may prove in England, it bears yet higher promise for his native country, the United States, where some of the most fertile soils have been exhausted, and can only be restored by a liberal administration of phosphates.—*The Field.* (London.)

A TREATISE ON THE STRENGTH OF BRIDGES AND ROOFS. By SAMUEL H. SHREVE, A. M., C. E. New York: D. Van Nostrand.

This work is designed to satisfy the demand for a text-book for technical schools, or for young engineers who divide their time between field practice and study. As an aid to the learner, this treatise seems all that can be desired.

While the work is complete in presenting analyses of all approved forms of bridge trusses, the mathematical investigations will be readily comprehended by any student of algebra. We will present a more complete analysis of the work in a future issue.

UNDERGROUND TREASURES. HOW AND WHERE TO FIND THEM. By JAMES ORTON, A. M. Hartford: Worthington, Dustin & Co. For sale by Van Nostrand.

The title to this little book explains its design. It affords a brief description of the useful ores of this country and their localities. A key to the detection of these different minerals seems especially valuable.

The book is widely demanded.

MISCELLANEOUS.

SOLDERING IRON AND STEEL.—The only methods by which it has been possible to solder iron and steel, have been complicated and expensive, and only profitable where there has been an absolute necessity of such a union. The best method we have seen where large and thick pieces of iron and steel are to be joined is as follows:—Sheet copper or brass is placed between the perfectly clean surfaces to be united, which are then tightly wired together. The joint is covered with wet clay free from sand, and dried slowly near the fire. When the mud is dry the joint is heated by a blast to a white heat and cooled suddenly if iron, slowly if steel. When brass is used, it requires less heat, of course, than copper. For objects of a moderate size hard brass solder is made by fusing together eight parts of brass and

one part tin. Soft brass solder is composed of six parts brass, one part zinc, and one part tin. For soldering small iron or steel articles a hard silver solder composed of equal parts of fine silver and malleable brass is used, the mass being protected by borax. Soft silver solder differs from this only in the addition of 1-16 part tin. Very fine and delicate articles are soldered pure either with gold or a gold solder composed of one part gold, two parts silver, and three parts copper.

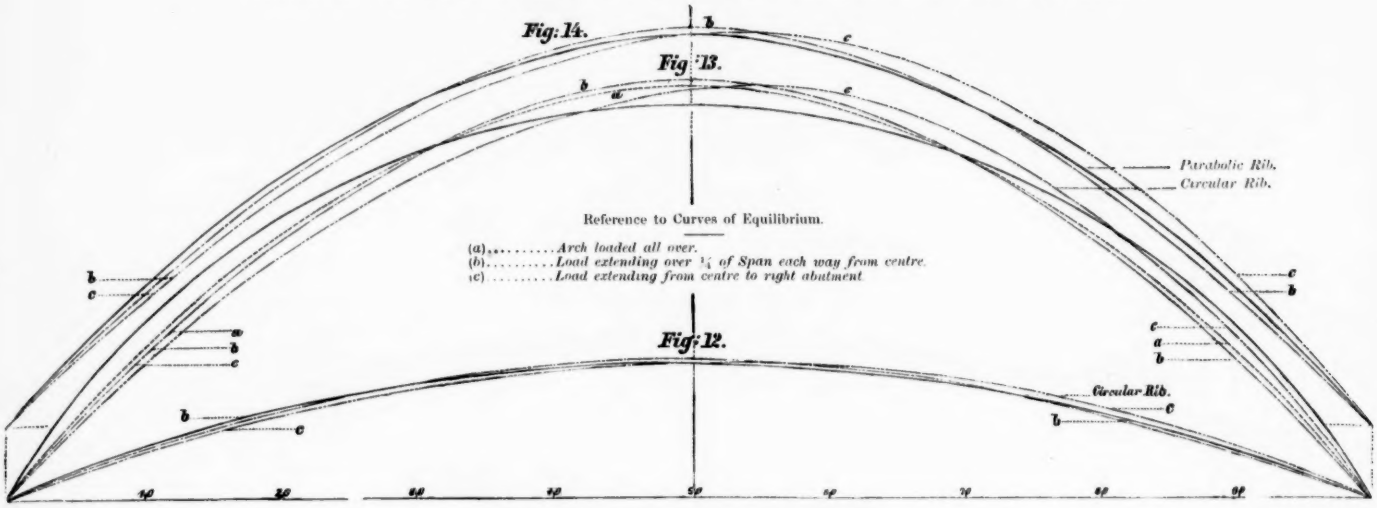
The new metallic substance, mentioned in our last issue as derived from the smelting of iron ores in a cupola in connection with magnetism, in a most direct and inexpensive manner solders iron and steel, or even two pieces of steel. We have in our office two pieces of Bessemer that have been united by it in such a way as to entirely hide the joint. But the process of steeling the iron as described there, can be used to a great advantage where it is necessary to have a substance part of steel and part iron. By immersing the part of the manufactured article that is to be steeled in the molten bath for a short time, it is changed into steel, while the part not immersed remains iron. There is a value in this invention that our manufacturers have not realized. We have specimens of the product and steel made from it in our office.—*Am. Manfacturer.*

EXTRACTION OF BISMUTH FROM CERTAIN ORES.—At the American Institute of Mining Engineers, Dr. T. Sterry Hunt said: I have lately had occasion to examine sulphuretted ores of bismuth both from Tudor, Ontario, and Latele, New Brunswick. The former consisted chiefly of bismuth-glance, carbonated at the outcrop, and within associated with some metallic bismuth, iron pyrites, and graphite, in a quartz gangue. In the second locality, where it appears to be present in considerable quantity, the veinstone is also quartz, but the associates of the bismuth-glance are chalcopyrite and galena. The treatment of such mixed ores in the furnace for the extraction of the bismuth could yield only a very impure product, and in view of the high price of the metal, I tried with success a wet method for the treatment of the ore, which is based on well known chemical reactions, and may, in some cases, be advantageously used. The pulverized ore is dissolved by heat in commercial nitric acid, and the remaining gangue washed by displacement, first with a little strong acid (which is used to attack a fresh portion of ore), and then with a moderate quantity of water, which is added to the first solution. This, if the excess of acid be considerable, may be partially neutralized by milk of lime or otherwise, and, then, after the addition of a little common salt, the bismuth may be almost totally precipitated by the addition of water, as a dense oxychloride, which by fusion with black flux, or a mixture of carbonate of soda and charcoal, yields at once pure metallic bismuth. The advantage of this method appears to be that it will permit the extraction of bismuth from mixed ores which cannot be advantageously treated otherwise, and moreover that it affects a separation of the bismuth from such foreign metals as would unfit it for pharmaceutical purposes. The economy of the process will evidently depend upon the cost of nitric acid at the place. It is possible that by a judicious calcination the bismuth ores might be converted into oxide, thus saving a considerable proportion of the nitric acid in the subsequent treatment. I have not, however, tried this modification. When a basic sulphate of bismuth is obtained in admixture with sulphate of lead, the two sulphates may be decomposed by boiling for a few minutes with a solution of carbonate of soda, and the resulting metallic carbonate being washed and dissolved in nitric acid, the bismuth is thrown down by simple dilution with water.

THE most remarkable evidence of the mechanical science and skill of the Chinese so far back as 1600 years ago is to be found in their suspended bridges, the invention of which is assigned to the Han dynasty. According to the concurrent testimony of all their historical and geographical writers, Sangleang, the commander of the army under Baou-tsoo, the first of the Hans, undertook and completed the formation of the roads through the mountainous province of Shense, to the west of the capital. Hitherto its lofty hills and deep valleys had rendered the communication difficult and circuitous. With a body of one hundred thousand laborers he cut passages over the mountains, throwing the removed soil into valleys, and where this was not sufficient to raise the road to the required height he constructed bridges which rested on the pillars or abutments. In another place he conceived and accomplished the daring project of suspending a bridge from one mountain to another across a deep chasm. These bridges, which were called by the Chinese writers, very appropriately, flying bridges, and represented to be numerous at the present day, are sometimes so high that they cannot be traversed without alarm. One still existing in Shense stretches four hundred feet from mountain to mountain, over a chasm of five hundred feet. Most of these flying bridges are so wide that four horsemen can ride on them abreast, and balustrades are placed on each side to protect travellers. It is by no means improbable (as M. Panthier suggests) as the missionaries to China made known the fact more than a century ago, that the Chinese had suspended bridges, that the idea may have been taken from thence for similar construction by European engineers.

THE DECAY OF STONE.—At the last ordinary meeting of the Manchester Literary and Philosophical Society, Dr. J. P. Joule, the President in the chair, Dr. R. Angus Smith said that he, like others, had observed that the particles of stone most liable to be in long contact with rain from town atmospheres, in England, at least, were most subject to decay. Believing the acid to be the cause, he supposed that the endurance of a silicious stone might be somewhat measured by measuring its resistance to acids. He proposed, therefore, to use stronger solutions, and thus to approach to the action of long periods of time. He tried a few specimens in this way, and with most promising results. Pieces of about an inch cube were broken by the fall of a hammer and the number of blows counted. Similar pieces were steeped in weak acid; both sulphuric acid and muriatic were tried, and the latter preferred. The number of blows now necessary was counted. Some sandstones gave way at once and crumbled into sand; some resisted long. Some very dense silicious stone was little affected.

ACTION OF A UNIFORMLY DISTRIBUTED LOAD ON A RIGID ARCH, WITH THE ENDS NOT FIXED.



STRESSES OF RIGID ARCHES.

SEE PAGE 289.